Reproduced by
Armed Services Technical Information Agency
DOCUMENT SERVICE CENTER
KNOTT BUILDING, DAYTON, 2, OHIO

AD-

1544

Reproduced From
Best Available Copy

UNCLASSIFIED

ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 99

10 October 1952

AD No. 15144
ASTIA FILE COPY

AD No. 15144
ASTIA FILE COPY

CONTACT LENSES: AN EVALUATION STUDY*

*Subtask under Environmental Physiology, AMRL Project No. 6-64-12-028.

MEDICAL RESEARCH AND DEVELOPMENT BOARD
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

REPORT NO. 99

CONTACT LENSES: AN EVALUATION STUDY

by

J. L. McGraw, Major, MC and J. M. Enoch, 2nd Lt., MSC

from

ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY
10 October 1952

*Subtask under Environmental Physiology, AMRL Project No. 6-64-12-028
Subtask, Contact Lenses Studies

-028

Report No. 99
Project No. 6-64-12-028
Subtask AMRL S-9
MEDEA

10 October 1952

ABSTRACT

CONTACT LENSES: AN EVALUATION STUDY

OBJECT

A comparative study of four types of contact lenses and spectacles to determine the relative merit of each, and thence to ascertain the feasibility of using them for selected members of the Armed Forces.

RESULTS AND CONCLUSIONS

A number of laboratory and field studies were conducted and tests were made to differentiate between the contact lens designs studied, and between these lenses and spectacles.

The four contact lens types studied were:

1. A plastic fluid corneal-scleral design.

2. A plastic corneal design.

3. A plastic ventilated fluidless corneal-scleral design.

4. A glass ventilated fluidless corneal-scleral design.

The study revealed that contact lenses have certain advantages in general military field activities but are not particularly superior in performance to spectacles when used for routine and clerical work. Contact lenses would be especially advantageous for use in inclement weather, Arctic duty, swimming, and violent activity. Corneal clouding is no longer a problem with the newer designs.

It was concluded that a vented fluidless corneal-scleral lens that permitted free flow of tear fluid and aeration of the cornea was superior to other designs. In the present status of lens construction, neither glass nor plastic was deemed better for fabrication. Each has its individual advantages and disadvantages.

Extended contact lens fitting time, cost and related problems as well as the necessity for individual motivation required prior to fitting, represent the major impediments to general utilization of contact lenses.

RECOMMENDATIONS

A. Study should be encouraged to improve the fitting technique and thereby simplify it and reduce the time required.

B. A technique for hardening or coating plastic with silicon or like substance to eliminate the necessity for wetting agents would be of tremendous value and studies along these lines should be encouraged.

C. The number of individuals skilled in the technique of fitting the newer types of contact lenses is extremely limited, and if the Army accepts them, a limited number of long term personnel should be schooled to do the fittings. Should the demand increase, these trained individuals could serve as a nucleus for the training of additional fitters.

D. Contact lenses can be recommended for:

1. Personnel who are extremely valuable to the Armed Forces because of their skill, training, and experience and whose visual acuity, with the usual visual aids, is not adequate to meet the requirements but may be with contact lenses. Such eye conditions as high myopia, high astigmatism, irregular astigmatism, corneal leukomata, keratoconus, aphakia, etc., are frequently adequately corrected with contact lenses.

2. Another group who might be retained or made available on the basis of adequate correction with contact lenses but are otherwise lost to the services are those with injuries to the face and lids that result in lagophthalmus, ectropian, corneal exposure, etc.

3. Personnel requiring visual correction whose field efficiency might be enhanced greatly if contact lenses were substituted for spectacles. Due to the many limitations of contact lenses, they should be restricted to outstanding individuals or situations such as Arctic duty divers, "Frogmen", etc.

Submitted by:

J. L. McGraw, Major, MC
J. M. Enoch, 2nd Lt., MSC

Approved: Ray G. Daggs
RAY G. DAGGS
Director of Research

Approved: Carl F. Tessmer
CARL F. TESSMER
Lt. Col., MC
Commanding

CONTACT LENSES. AN EVALUATION STUDY

I. INTRODUCTION

The object of this project was to make a comparative study of four types of contact lenses and spectacles to determine the relative merit of each and thence to ascertain the feasibility of using them for selected members of the Armed Forces.

The potential advantages of contact lenses to military personnel would appear to be numerous if such lenses proved practical. The possible utilization by the Armed Forces of large numbers of men previously disqualified or on a limited duty status served as one reason for undertaking this study. Furthermore, men who ordinarily wear spectacles could perform better in inclement weather, and participate in field duties previously considered impractical. The danger of lost, broken, or fogged spectacles might be eliminated. Light reflections from spectacles, which may reveal positions to the enemy, could be eradicated. The problem of using spectacles with sighting equipment as well as the use of inserts in gas masks might well be simplified. Contact lenses themselves offer numerous advantages in increasing the visual field, elimination of corneal astigmatism, etc.

Among the disadvantages to be considered would be the expense, fitting and adaptation time, the development of corneal haze and the resultant subjective fogging of vision and chromatic halo, variable tolerance and photophobia, ocular irritation etc. However, in view of recent advances in design and manufacture, the potentialities of contact lenses have deemed a study such as this advisable.

II. EXPERIMENTAL PROCEDURE

The problem has been approached from two aspects. First, one contact lens type was evaluated against another; and second, contact lenses were compared in performance with spectacles. Four types of contact lenses were selected for this study.

The lenses and spectacles were fitted to ten selected enlisted men who were subjected to a series of tests, both in the laboratory and in the field.

The laboratory tests included subjective and objective measurements of halo brightness and time, corneal turbidity, entoptic fields color vision, visual acuity and tolerance to light at different levels of target and surround illumination, depth perception, binocular vision and fusion tests, dark adaptation, and clinical appearance of the eye.

Attempts were made to duplicate most of the possible situations that a military man might encounter in routine life and on the field of battle. Included in these were kitchen police, guard duty, artillery and small weapons firing, tank driving, parachute jumping, swimming, etc. The lenses were tested under climatic extremes in the hot and cold rooms of the laboratory, and at simulated high altitudes in the low pressure chambers at the Wright-Patterson Air Force Base.

A. Subjects

Ten enlisted volunteer soldiers were selected to serve as subjects. They were chosen primarily for their diversified refractive errors, secondary considerations being intelligence and personality. Table 1 shows the age, visual acuity, and cycloplegic refractions of the subjects. Each subject was fitted with spectacles and the four types of contact lenses.

B. Lenses

The selection of the particular contact lenses to be studied was difficult. For obvious reasons, it was impossible to study the hundreds of variations of lenses for which patents are held. An attempt was made to select lenses that represent various principles of design and fitting. The work of Smelser (1) and Finkelstein (2) served as a valuable guide.

1. The conventional fluid type plastic lens was chosen as one lens to be studied since it represents one of the pioneers in the field and most of the experimental work has been concerned with this lens.

The lens was fitted to the subjects by the molding technique at the Obrig Laboratories in New York. The lens is constructed with three principle curvatures, i.e., optic or corneal, limbal clearance, and haptic or scleral (Fig. 1). The time required for the fitting of the ten subjects averaged three hours and thiry-three minutes in a total of four visits (Fig. 2).

The solution used with this lens was 1-1/2% sodium bicarbonate (USP) (2, 3) made fresh daily with triple distilled water. Since the lenses are plastic, a wetting agent is required. A solution of 1/2% methyl cellulose and Zephiran (Benzalkonium Chloride) was used.

2. The corneal plastic lens was included in the study because of its tremendous surge of popularity in recent years, as well as for its simplicity of design and relative ease of fitting. Mr. Kevin Tuohy, of Solex Laboratories, originator of this particular design, did the fitting. The lens has a bevelled edge corneal portion (Fig. 1). The fitting is based upon ophthalmometer readings, corneal size, and lid aperture. The time required for the fitting of this lens to the ten subjects averaged two hours and fifty-five minutes in a total of five visits (Fig. 2).

The lens must be moistened with a wetting agent before insertion, but otherwise no fluid is required other than the natural tears. T' wetting agent employed was a solution containing 1/2% methyl cellulose and Zephiran.

3. The fluidless glass ventilated lens, designed by Dr. Josef Dallos of London, England, was used as an example of a glass precision fitted lens. This is a minimum clearance lens which utilizes a capillary layer of tears as its lubricating solution (Fig. 1). It is a large diameter lens that has little rotation with ocular version. There are two principle curves, optic and haptic, and a small limbal clearance. A small circular vent about 1 mm. in diameter is placed at the limbus, usually just below the midline on the temporal side. The location of the vent, however, is varied so as to allow proper aeration of the cornea. Extreme care and experience are required in the fitting of this lens, as there must be a constantly changing air bubble present that must not interfere with vision. There can be no corneal or limbal pressure. In the fitting of this lens, Dr. Dallos draws from a collection of some three thousand shells, and by trial and error selects a lens approximating that desired and then by grinding tight areas and building up loose areas with wax, proceeds with the fitting process. As the lenses are glass, and there is constant danger of breakage, he makes repeated plaster and brass molds as the fitting proceeds. When the t seems satisfactory, a limbal hole is drilled. Several trials may be necessary to assure proper positioning of the air bubble. The fitting time averaged about nineteen hours in a total of twenty-eight visits (Fig. 2).

Since these lenses are made of glass, a wetting agent is not required. The lenses are simply washed with water and placed in the eye. The natural tear fluid fills the space between the lens and the cornea, leaving a bubble the size of which varies with the rotations of the eye.

4. A fluidless plastic ventilated lens was selected as the fourth lens for this study. This lens is made commercially under the name of "Lacrilens" by the Obrig Laboratories of New York. This is a molded plastic lens made from a casting of the eye (Fig. 1). A notch is made in the lens inferiorly which extends from the periphery of the haptic to the limbal area in the six o'clock meridian. The notch generally is covered by the lower lid except when the eyes are directed upward. It necessitates frequent upward rotation of the eye to permit drainage of tear fluid and for aeration of the cornea. When the eyes are in any position other than upward rotation, the bubble should be minimal and the area between the lens and the cornea almost completely filled with tear fluid. There are three principal curvatures in this lens, i.e., optic, limbal clearance, and haptic. Fitting time for the ten subjects averaged eight hours and forty-five minutes in a total of eleven visits (Fig. 2).

5. Standard army issue spectacles were used in this study. These are toric ground "ful-vue" shaped lenses set in either nichrome, gold, or clear plastic "ful-vue" frames. Prescription was determined by cycloplegic and post-cycloplegic refraction.

C. Test Program.

A program of testing was established to cover both field and laboratory work. The field tests were arranged with the intent of exposing the subjects to as many of the conditions as possible that are encountered in routine army life and on the field of battle. Since four contact lenses and spectacles were to be compared in performance, the program was divided into five cycles. To be assured that each lens was equally exposed to the variable seasons and their elements, the ten subjects were divided into groups of two, each pair wearing a different lens (Table 2). Whenever possible, equipment for testing was carried into the field. This, however, was frequently impractical and the field observations were confined to the subjective reactions of the individual subjects.

The subjects joined with basic training units at Fort Knox for exercises that necessitated acute vision, physical strain, and exposure to the elements. They performed such exercises as tank driving (day and night), rifle and machine gun firing, infiltration and close combat, hand-to-hand combat, etc. Performance was checked while wearing gas masks, while swimming, and while on guard duty and kitchen police. To observe the effect of the jolt of an opening parachute, the facilities of the mock-up training towers at Fort Campbell, Kentucky were used. Tests were performed in the laboratory cold room at -40° Fahrenheit and in the hot room at +120° Fahrenheit. In the low pressure chambers at Wright-Patterson Air Force Base at Dayton, Ohio, the effects of a simulated altitude of twenty thousand feet were tested. The effects of explosive decompression also were observed.

Each cycle of testing covered approximately two months. A typical cycle is shown below.

March	8-24	Adaptation to new lenses.
	24-28	Laboratory studies.
	24-25	Photometer and adaptometer.
	26	Halometer, entoptic field, color, one foot Lambert visual acuity, surround and target tolerance, phoria.
	27	Halometer, entoptic field, color, twelve foot Lambert visual acuity, surround and target tolerance, phoria.
	28	Halometer, entoptic field, color, one hundred foot Lambert visual acuity, surround and target tolerance, phoria.
	31	Gas masks.
April	1-3	Low pressure chamber at Wright-Patterson Air Force Base.
	4	Swimming.
	7-18	Field Tests.
	7-8	Tank Driving.

April	9	Combat in towns.
	10	Infiltration and close combat.
	11	Service firing (tank).
	14	Rifle transition.
	15	Confidence course and rifle known distance firing.
	16	Individual tactical training.
	17	Browning automatic rifle transition.
	18	Hand-to-hand combat. BAR firing known distance.
	21	Guard duty.
	22-23	Cold Room (-40° Fahrenheit).
	24-25	Mock-up parachute jump at Fort Campbell.
	28	Kitchen police.
	29-30	Hot room (+120° Fahrenheit).
May	1-2	Laboratory studies.
	1	One foot Lambert visual acuity, surround and target tolerance.
	2	Twelve and one hundred foot Lambert visual acuity, surround and target tolerance.

An adaptation period of two weeks seemed adequate for these subjects who previously had become familiar with each lens during the fitting period.

After completion of three cycles an evaluation was made and it seemed unnecessary to repeat all of the field studies. Only those phases which revealed pertinent findings in the first three cycles were repeated in the last two cycles.

III. RESULTS AND DISCUSSION

A. Laboratory Studies

In the laboratory studies several of the instruments devised by Finkelstein (2) were employed. Consideration was given to the usual aids for ocular testing and those that appeared to have value for this comparative analysis were employed.

1. Halo brightness and halo time

Until recently, corneal haze has been the major problem associated with contact lenses. This haze causes a subjective visual fogging and a chromatic halo. The aim of this particular study was to determine the rate of development and the brightness of the chromatic halo produced by each lens. Several theories have been presented as the possible cause of this diffraction phenomenon. The most recent work in this field was conducted by Finkelstein (2) who has designed an instrument to measure both size and brightness of the halo. This instrument, known as the Halometer (Fig. 3), contains as a light source an S-4 type sunlamp which is filtered so that the subject sees an almost monochromatic green light of high intensity through a small aperture in the instrument. Through a somewhat larger aperture to the rear of the source, similarly filtered light passes through a variable and two fixed polaroids and falls upon a screen at the rear of the Halometer. The subject is instructed to stand at a distance from the apparatus so that the point of maximum intensity of his halo appears at a distance of 27 cm. from the central light source. This falls just within the comparison arc which has an inner diameter of 30 cm. and through which the rear screen is viewed. The subject stands at approximately sixteen feet from the instrument. By changing the orientation of the variable polaroid the subject makes a brightness match to his halo. The technique employed in this study was a slight variation from that used by Finkelstein in that a standard halo position was used for all subjects, rather than allowing each subject to pick his own area of the halo for comparison. Nine readings were taken hourly after the subject first observed the development of a halo. A mean was taken and these data were transposed into percentages of light transmitted through the polaroid plates. Thus the results were relative measures of halo brightness.

The average intensity of the halo brightness developed while wearing the fluid lens did not quite equal that reported by Finkelstein, but the general pattern was the same. From the graph (Fig. 4), it is apparent that there was a gradual increase in halo brightness with wearing time of the fluid lens. Only on rare occasions did measurable halos develop with the other type lenses. Among these exceptions were instances when an isolated individual wearing one of the ventilated lenses would have a blockage of the vent by mucus or edematous conjunctiva. This was a transient halo that disappeared when the obstruction was removed. Transient halos were reported by several individuals wearing the ventilated lenses while swimming. In none of these cases were the halos intense enough to be measured.

The halo time was defined as the time after lens insertion when the diffraction pattern associated with corneal haze became sufficiently organized to form a chromatic ring. This was a significant reading and was rather consistent from day to day if conditions were held constant. Thus, for example, in the cold, hot, and low pressure rooms, the halo time gave an excellent guide as to the rate of corneal changes. The instrument used for the detection of halos, had a microscope illuminating lamp as a light source. This device emitted an extremely bright beam of relatively white light through its 10 mm. aperture which was viewed from a point approximately twenty feet from the source.

Since in many test situations it was impractical to transport the halometer from the laboratory, it was necessary to limit the test to halo appearance time. The average halo appearance time under standard conditions was two hours and fourteen minutes (Fig. 5). This varied with climatic extremes. In the cold room, the average appearance time was delayed (three hours and nineteen minutes). The halos appeared slightly earlier than normal in the hot room (one hour and fifty-two minutes). In the low pressure room, the average time was two hours and fifteen minutes.

Under standard conditions, the appearance time and relative increase in brightness of this diffraction phenomena was quite constant for the individual, although there was some variation between subjects. The occasional appearance of halos when the vent in the ventilated lenses became obstructed demonstrated the necessity for free flow of tear fluid and aeration of the cornea (1). The appearance of transient halos while swimming may be ascribed to the low tonicity of the water that circulated under the lens (2).

The earlier appearance of halos in the hot room and their delayed formation in the cold room might possibly be explained by some variation in the metabolism of the corneal tissue at different temperatures.

In view of the work of Smelser (1) it had been anticipated that, with the reduced oxygen in the low pressure chamber, halos might have become apparent to individuals wearing contact lenses and possibly appear earlier with the fluid lenses. Since no halos appeared with the fluidless lenses and there was no change in the development time in the fluid lenses, it must be assumed that there was still adequate oxygen at the simulated altitude (20,000 ft.) to maintain normal corneal metabolism during the time tested.

2. Corneal turbidity

This is a measure of corneal haze development. The basic instrumentation used was an adaptation of a Bausch and Lomb slit lamp in which a telemicroscope was substituted in place of the corneal microscope (Fig. 6). By optically splitting the beam of light entering the telemicroscope, photometric measurements can be made after the operator aligns the instrument in its proper position. This apparatus was designed by Finkelstein (2) and provides for exact replication of the positioning of the slit of light (the brightness of which is reduced by a #1 neutral density Wratten filter) upon the eye and the telemicroscope detector which is set to receive the light reflected and scattered by the cornea.

The photoelectric measurement of this light results in a relative measure of corneal haze. The cornea normally reflects a certain amount of light and an increase in turbidity causes an increase in reflection. Four readings were taken hourly throughout the day and the mean was taken of each set of readings. The photometer part of the apparatus consists of a Farrand Electron Multiplier and a voltage regulator with ballast employed in the slit lamp circuit. The standardization is accomplished with a specially adapted Macbeth Illuminometer.

Certain changes were made in the instrumentation and technique employed by Finkelstein. A monitoring unit was added between the slit lamp and the focusing objective. The purpose of this was to assure a constant amount of light reaching the cornea, where-as formerly only the electrical properties were kept constant. It was found that in order to maintain standard illumination, the amperage had to be changed frequently during the day. The deterioration of bulb and filament caused electrical variations. Hence the monitoring unit seemed to be a valuable addition. A piece of plain, clear glass inclined 45° to the plane of illumination was placed in the apparatus. This permitted a certain amount of the beam to be reflected vertically and after passing through a #3 neutral density Wratten filter and a small aperture, the light would fall upon a photo-cell.

The photo-electric monitor circuit (Fig. 7) consists of two sections, a stabilized high voltage power supply for all but the last stage of the 931-A multiplier photo-cell used to monitor the light intensity, and a regulated low voltage power supply and amplifier. The amplifier is a bridged vacuum tube voltmeter. Two 5693 tubes are used as arms of the bridge, one being operated at a fixed gain as a reference and the other tube controlled from the 931-A photo-cell. A voltage divider is placed across the output of the 931-A so that the unit may be used over a wide range of light intensities. A 50 micro-ampere meter is placed between the plates of the two 5693 tubes to indicate the relative intensity within the selected range. The relative brightness of the beam can be read from a meter in micro-amperes (4).

Another change in technique was the use of a standard chin rest rather than the molded bite plate employed by Finkelstein. It was found that it was possible to replicate the findings and speed up the testing with this simplification. This allowed for one setting of the instrument and allowed freer manipulation of subjects.

The objective observation of corneal scatter as measured on the modified slit lamp photometer revealed very minimal changes with all contact lenses for the time tested except the fluid type lens (Fig. 8). The corneal scatter increased with the time the fluid lens was worn. Finkelstein ran similar studies on the fluid and corneal lenses (2), with approximately the same results. He also demonstrated that normally no change in corneal scatter occurred when no contact lenses were worn.

The photometer reading is a composite of light reflected by the corneal optical surfaces and light scattered by opaque or semi-opaque bodies within the cornea. Thus normally a certain amount of light is measured by the photometer. With the development of corneal haze the cornea becomes more translucent and the amount of light scattered and reflected by an increasing number of relatively opaque bodies increases. Consequently there is a good correlation between corneal haze and corneal scatter. Therefore, it can be assumed that no measurable corneal haze developed under normal conditions except when the fluid lenses were worn. The wearing of the fluid lens produced a gradual increase in corneal scatter with corneal haze.

3. Visual acuity

It was noticed during the pilot studies, while testing subjects manifesting corneal haze, that a difference existed between the vision recorded in a semi-darkened test room and the apparently poorer vision noticed shortly afterward in the brightly illuminated laboratory. Thus further studies seemed indicated. Since this drop in vision apparently occurred where high levels of ambient or surround illumination existed, test apparatus was constructed which provided for control of both target and surround illumination.

The testing was conducted at fifty centimeters and at twenty feet using the Landolt-C as the test target. For the testing at fifty centimeters, fourteen slides were made from a photographically reduced Landolt-C in a range of sizes from 20/10 to 20/200. The photographs were of maximal contrast. The slide holder was fitted into a large ball bearing mount which provides complete rotation of the centered target (Fig. 9, 10).

The target area of the apparatus is that subtended by an angle of four degrees, forty-three minutes and eight seconds of arc and vision is limited by the diameter of the bearing mount. It is illuminated from the rear by a 60 watt Mazda lamp, and the light is diffused by a piece of Belgian flashed opal glass. The brightness of the target at the various transformer settings was calibrated with a General Electric Luckiesh-Taylor Brightness Meter, and ranged from 0.109 foot Lamberts to 1284.4 foot Lamberts. These and all intermediate readings were based upon the mean of nine readings. To prevent wall reflection, the sides of the passage through which the target is viewed are painted black and three large reflection stops are placed at intervals (Fig. 10). This passage extends into the surround illumination box just far enough to prevent any illumination from the box falling upon the target. A shutter is placed in front of the light source so that the target may be rotated without the subject viewing it.

When the apparatus was used for testing at twenty feet, the target illuminator and the viewing passage were removed, leaving merely the surround section with a 4"x4" aperture in the box. An instrument manufactured by Yamakosi Seisakusyo, Tokyo, was used for the target in this case. It is a Landolt-C vision test apparatus providing ten targets ranging from 20/8 to 20/42, to which were added four photographically reproduced Landolt-C charts from 20/59 to 20/162, which fit into a special holder on the instrument. The direction of the C and the target size can be changed by use of controls (a planetary gear system) in the rear of the apparatus. Illumination is provided by two shielded 60 watt Mazda lamps and controlled by a rheostat. The targets reflect an average of 73.3% of the light illuminating them, as determined by taking a mean of the percent reflectance at intervals of twenty millimicrons over the range of four hundred to seven hundred millimicrons.

Calibration of target brightness was accomplished with the Luckiesh-Taylor Brightness Meter. Both the target and surround variable transformers were connected to a constant voltage transformer.

The surround is actually provided by a glass box within a box. The inner box which the subject views is constructed of Belgian flashed opal glass on all but one side. Thus, illumination reaches the eyes directly from above, below, left and right. Directly ahead, the subject views the target area which is set into a 4"x4" aperture in the white front wall of the apparatus. The outer box contains four 60 watt Mazda bulbs, one centered above each opal glass panel. These serve to illuminate the opal glass. The base of the glass section of each bulb is set six inches from the inner glass panel. The four bulbs are electrically joined in parallel to a variable transformer. The subject's head is placed into the box in a manner such that he is surrounded by ambient illumination. His position is maintained by a lucite molded headband which is so positioned, that when the subject is properly aligned, his eyes are at the desired distance from the target. The position and shape of the headband was determined by mean cranial measurements of the ten subjects.

Calibration presented a difficult problem, since although the light box is symmetrical, it is neither cubical nor spherical.* (The rectangular shape was determined by the fact that provision had to be made to allow space for a double fold of an oxygen respiratory tube used in the low pressure room). The essential problem was to

*Mr. Sylvester Guth of the General Electric Company was very kind in offering his advice on this and associated problems.

determine the level of ambient illumination at the several variable transformer settings. Since almost every point within the box revealed a different level of brightness measured with a General Electric Luckiesh-Taylor Brightness Meter, it was decided that probably the best method would be to measure the integrated level of illumination with a Weston Foot-Candle Meter pointed at the darkened target from the position of the monocular eye. The illumination varied from zero to three hundred and fifty foot candles. A rather complete analysis of the brightness existing in the light box was made at the one hundred foot candle level. Measurements were made to determine if equal brightness existed at symmetrical points in the light box and if a change in variac setting would result in a directly proportional change in brightness at the several points. Proportional change and symmetry were found, and a diagrammatic view looking into the light box is presented to show the brightness at various points in the box at the one hundred foot candle level (Fig. 11).

Testing was conducted at various brightness settings of target and surround. During each of the five cycles, each test combination was conducted on two days. To determine the effect of varying target brightness, three basic levels were chosen--one, twelve, and one hundred foot Lamberts. The twelve foot Lambert level was used since it has been recommended by the Subcommittee on Procedures and Standards for Visual Examinations for the Army, Navy-NRC Vision Committee (5). It will be noted that the chosen levels are approximately one log unit apart.

Most of the testing was conducted at fifty centimeters since only one operator was necessary at this test distance. Testing was done only for targets of twelve foot Lamberts at the twenty foot distance. The surround illumination levels of zero, one hundred, two hundred, and three hundred foot candles were rather arbitrarily chosen to determine the effect of succeeding levels of ambient illumination.

In the low pressure chamber and the hot room, testing was done with targets at the standard twelve foot Lambert level. Testing obviously was limited in the cold room so readings were taken at this same level of target brightness immediately after leaving the cold room.

SPECTACLES:

The testing of visual acuity with spectacles at twenty feet revealed that virtually no change took place during an eight hour period. The variation of surround illumination seemed to have significant effect. These findings are different in degree from those of Lythgoe (6) but it is believed that this is due to differences in method of testing.

Testing at twenty feet (Fig. 12) resulted in readings that were almost identical with those taken at fifty centimeters (Fig. 13) with a twelve foot Lambert target level. The readings averaged 20/19 for all test conditions.

By increasing target brightness, (Fig. 14), visual acuity was increased only slightly at all levels; and a decrease in target brightness (Fig. 15) apparently caused a very minimal decrease in visual acuity. These changes are insignificant.

The data taken in the hot and cold room (Fig. 16), while slightly less consistent, revealed virtually no change in visual acuity. Vision in the cold room was just slightly better than that in the hot room. One great disadvantage of spectacles in the cold room was the frosting of lenses that occurred shortly after entering the cold and the steaming of lenses on returning to a warmer atmosphere. To maintain adequate vision in the hot room, it was necessary to clean the lenses frequently because they became spotted with perspiration.

Visual acuity in the low pressure chamber (Fig. 17) was practically the same during a seven hour period as at normal atmospheric pressure.

Visual acuity with spectacles remained virtually constant throughout the day. Variation of target brightness from one foot Lambert to one hundred foot Lamberts, and variation of surround illumination from zero to three hundred foot candles had little effect on visual acuity. The very minimal changes noted in the hot room could have been a secondary result of the generalized languor that is commonly associated with prolonged exposure to high ambient temperatures. The "mechanical" difficulties of frost, steam, and perspiration put spectacles at a disadvantage when worn under climatic extremes.

DALLOS AND LACRILENS:

The findings with the Dallos and Lacrilens were almost completely identical. Visual acuity, tested at twenty feet (Fig. 12) and at fifty centimeters (Fig. 13) with twelve foot candle surround illumination, averaged 20/20 throughout the entire testing period which in some instances lasted as long as fifteen hours. Varying the surround illumination had little effect on visual acuity despite the prolonged wearing time. There was a very minimal drop in visual acuity noted after wearing the Dallos lens for six hours when the target illumination was reduced to one foot Lambert in the presence of an increased surround illumination (Fig. 15). This drop never exceeded a change of more than that from 20/20 to 20/27. At the one hundred foot Lambert level (Fig. 14), even this slight change was not noted.

In the hot room (Fig. 16), very slight changes in visual acuity were noted. The change never exceeded more than that from 20/20 to 20/25. Cold room readings revealed (Fig. 16) virtually no change in visual acuity. In testing in the low pressure chamber (Fig. 17), no changes were noted throughout the period of observation.

There was noted a very slight drop in visual acuity immediately following the removal of the lenses (Fig. 12). This was tested at twelve foot Lambert target brightness with zero surround illumination. The average drop did not exceed 20/22 from a wearing base value of 20/17 and can hardly be considered significant.

Visual acuity with the Dallos and Lacrilens remained essentially normal throughout the extended testing periods. At no time did a change in visual acuity exceed a drop of more than that from 20/20 to 20/28, and this was noted only at a low target illumination level and a high surround illumination in the hot room. This indicates that only minimal corneal changes occur when these lenses are worn

FLUID LENSES:

Visual acuity tested at twenty feet with a target brightness of twelve foot Lamberts with various levels of surround illumination while wearing the fluid lens is represented in Fig. 18. With the surround illumination at zero, the reduction in visual acuity was relatively slight despite the existence of a deep corneal haze. With the introduction of surround illumination, there was a significant drop in visual acuity in the presence of deep corneal haze, which apparently was proportional to the depth of the haze and the brightness of the surround. With the surround illumination at zero, the mean visual acuity reading had fallen from 20/17 to 20/29 within the seventh hour; while within a similar period with the surround illumination at three hundred foot candles, the fall was from 20/19 to 20/117. Visual acuity remained essentially at a constant level from the time of insertion of the lenses until a time that was almost coincidental with the appearance of the chromatic halo.

When visual acuity was tested at fifty centimeters (Fig. 19) with a target brightness of twelve foot Lamberts and varying surround illuminations, the results were essentially of the same order as those found under similar lighting conditions at twenty feet. While the effects were comparable, they were not as extreme. Here again there was little drop in visual acuity with no surround illumination while with a surround illumination of three hundred foot candles, the visual acuity dropped from 20/20 to 20/87 with the development of corneal haze. This change was apparently proportional to the depth of the corneal haze and the brightness of the surround.

The irregularities in this and other visual acuity charts do not necessarily indicate violent fluctuations in visual acuity, for all of these irregularities can be ascribed to individual subjects who experienced difficulties of one type or another, such as irritation and photophobia, which resulted in early removal of the lenses. In general, individual curves of visual acuity revealed gradually progressive changes. The charts presented, however, represent the composite means of individual results taken within hourly periods.

The effects of varying the target brightness while wearing the fluid lens are represented in Fig. 20 and 21. When the target brightness was reduced to one foot Lambert and the surround illumination varied from zero to three hundred foot candles, the effects were comparable to those seen with target brightness values of twelve foot Lamberts, but were greatly magnified. Similarly, when the target brightness was increased to one hundred foot Lamberts, the effect was greatly reduced.

The drop in visual acuity apparently was more closely related to corneal haze at the lower levels of target brightness

If one examines the readings taken immediately after emerging from the cold room after both six and eight hour exposure periods, it will be seen that almost no change in visual acuity had taken place (Fig. 22).

On the other hand, the hot room data (Fig. 22) reveal that the changes in visual acuity, with an increase in surround illumination, occurred sooner at 120° Fahrenheit than at the normal laboratory temperature of 72° Fahrenheit. Again, the halo time served as a coincidental factor with the drop in visual acuity. In the hot room the chromatic halo appeared sooner than normal, and in the cold room its appearance was delayed.

The findings in the low pressure chamber (Fig. 23) were similar to those for normal conditions (Fig. 19).

It had been noted that there was blurring of vision after removal of the lenses, especially in the presence of corneal haze. Tests were done to determine the time required for restoration of normal vision (Fig. 18). Results showed that there was an immediate drop in visual acuity upon removal of the lenses even with no surround illumination. However, within thirty minutes after removal, the vision had returned to normal. Similar testing was done at the fifty centimeter distance with different levels of illumination and the results were essentially the same. The more intense surround illumination (one hundred foot Lamberts) caused proportionately greater blurring, but as the corneal haze cleared, the effect of the ambient lighting was reduced and the vision returned to normal with all levels of surround illumination within thirty minutes.

The visual acuity after inserting fluid lenses was not significantly different from that while wearing spectacles. However, after approximately three hours of wearing time, the visual performance with fluid lenses began to fail. Since the only known changes in the refractive media are said to occur in the cornea, it must be assumed that these were responsible for the reduction in vision. Smelser (1) has shown in animal experimentation that edema and thickening of the cornea occurred after fluid lenses were worn. Donaldson (7) found similar results with humans. The thickening of the cornea would have little effect on visual acuity while the fluid lenses are being worn, since the indices of refraction of fluids on either side of the cornea virtually negate the different refractive power of the cornea. It is assumed that a temporarily increased thickening of the cornea might have occurred in the present studies and was at least partially responsible for the greater degree of visual impairment immediately after the lenses were removed.

Another change that occurred in the cornea while wearing the fluid lens was the development of progressive corneal clouding, which probably was the main cause for decreased visual acuity while the lenses were worn and immediately after their removal. This clouding of the cornea tends to scatter incident light resulting in a veiling glare. Many workers in the field of lighting (8, 9, 10, 11) have found that veiling glare has three main effects. These are: reduction in contrast, photophobia, and raising the level of light adaptation. The amount of veiling glare created is dependent upon the depth of the haze and the quantity and extent of light incident to the eye. Since visual acuity is partially dependent upon discrimination between the target and its immediate surround, any factor such as veiling glare that tends to reduce the contrast will result in reduction of visual acuity. In this experiment, the variable illumination of the target, whose area was of small extent, apparently induced minimal veiling glare, while the extended surround illumination has a pronounced effect.

These hypotheses were demonstrated at both the twenty foot and fifty centimeter test distances with the fluid lens. The drop in visual acuity appeared shortly after the first appearance of the halo, which seemed to indicate that a depth of haze just slightly greater than that existing at the time of the halo was necessary to produce the reduced acuity. This process seemed to be accelerated under hot room conditions and retarded in the cold room as was the halo appearance time. In the low pressure chamber, there was little variation in results from those obtained under normal conditions.

The differences in visual acuity seen in the various levels of one, twelve, and one hundred foot Lamberts of target brightness were undoubtedly the result of contrast differences that existed between the target and the immediate surround in the presence of veiling glare.

In the presence of a constant surround illumination and with corneal haze and the resultant veiling glare, the effect was lessened at the higher levels of target brightness. The veiling effect was unchanged, but at the increased level of target brightness, the contrast was greater and therefore the effect on visual acuity was lessened. It was only when the difference in contrast fell below the level of contrast sensitivity that the visual acuity lessened. Thus the visual acuity at the target brightness of one hundred foot Lamberts was better than that at one foot Lambert in the presence of a constant veiling glare. Therefore, visual acuity may be assumed to be relative to the contrast difference between the target and its immediate surround.

The immediate drop in visual acuity upon removal of the fluid lenses may be assumed to have been due to both corneal thickening and haze. Visual acuity was restored within a half an hour.

TUOHY LENS:

The results of the visual acuity tested while wearing the Tuohy lens were quite bizarre. It was found that certain subjects experienced considerable discomfort while wearing this lens, and as a result, many of the findings were erratic. In order to present the results, the data were divided into two groups. Group A included the data of subjects who were unable to tolerate their lenses for four hours, and Group B included the data of those who wore the lenses more than four hours. Group A and B did not necessarily include the same subjects in each test since individual tolerance varied from day to day. It was found that if the individual subject was able to wear his lenses comfortably for four hours, he could frequently continue wearing them for the completion of the test period. It was for this reason that the arbitrary division of the data was made at four hours.

Visual acuity, as tested at twenty feet, revealed very little change in those who wore the lenses comfortably, Group B, (Fig. 24). Group A, however, revealed marked and rapid decreased in visual acuity which was greatly accentuated by the introduction of surround illumination. It will be noticed that the average removal time was two hours and one minute. Readings for Group A taken after that time show a return to the normal because those with the greatest irritation had removed their lenses.

Results of visual acuity tests at fifty centimeters at the twelve foot Lambert target level were similar to those of the tests at twenty feet, but the changes were not as extreme for Group A (Fig. 25). The slight irregularities in Group B were due primarily to the inclusion of one subject who had discomfort, but was able to wear his lenses for five hours.

The findings at the one foot Lambert target level appear at first glance to be quite confusing (Fig. 26). Group A experienced considerable irritation and therefore had short wearing times and rapid drops in visual acuity which were accentuated by increased ambient illumination. The average removal time in this group was one hour and fifty-two minutes. The marked irregularity seen in Group B was due primarily to two subjects who wore the lenses more than four hours despite some discomfort and poor vision. The two marked variations were produced by these two subjects removing their lenses at different times. Had Group B been graphed without these two individuals, the visual acuity would not have dropped below 20/30 at any time.

With a target brightness of one hundred foot Lamberts, the results again were similar (Fig. 27). In Group A the visual acuity again dropped rapidly, especially with increased surround illumination. The irregularity seen in the graph of Group B was due to the readings for one individual who wore his lenses beyond the four hour period despite discomfort.

The results in the hot and cold room again are similar to the above findings (Fig. 28). The findings were more extreme but of the same pattern.

The low pressure chamber findings follow the same pattern (Fig. 29). The slight drop in visual acuity as seen in the graph was the result of one individual who experienced difficulty toward the end of the experiment.

Visual acuity tested at twenty feet after the removal of the lenses, revealed that Group A subjects returned to normal within four minutes (Fig. 24). The unexpected drop in visual acuity in Group B was caused by one individual whose vision was frequently better with contact lenses than with spectacles. This difference is probably not significant.

The number of subjects in Groups A and B was not equal or constant. The individual tolerance varied considerably from day to day and with the test being conducted. On an average, approximately two-thirds of the subjects in each test fell into Group A. In tests in the hot room and with high target brightness, this group was somewhat smaller. Of Group B, less than one-half could tolerate the lenses for eight hours. While the individual tolerance was variable from day to day, on an over-all basis the groups more frequently consisted of the same individuals.

It seems apparent that the corneal lenses, as worn in this experiment, were poorly tolerated. In all the tests, approximately one-third of the subjects could tolerate the lenses for more than four hours. Of these, usually less than half could complete the test runs of eight or fourteen hours.

The visual performance with this lens seemed to be dependent upon tolerance, which in turn was dependent on ocular irritation and its influencing factors. This was well demonstrated by individuals in Group B who comfortably tolerated the lenses. There was little reduction in visual acuity, even after extended wearing time. Another demonstration of this is shown in Fig. 24, by Group A where immediately after the source of irritation was removed, the vision returned to normal. It can be assumed from this that the visual impairment was not the result of corneal haze, as in the fluid lens, but was secondary to the irritation which resulted in extreme photophobia, tearing, and spasms of accommodation. Heat and increased surround illumination tended to aggravate the condition. Cold seemed to have a somewhat beneficial effect in reducing the subjective ocular irritation. The results in the low pressure chamber showed little subjective variation from normal.

4. Photophobia

It became apparent from the pilot studies on visual acuity, that photophobia frequently became a factor of considerable influence. Therefore, an attempt was made to evaluate this phenomenon. In the field studies, this effect when noted was recorded as a subjective comment, thus being only qualitative in nature. However, in the laboratory an attempt was made to obtain some quantitative measure of tolerance to light. The equipment developed for the testing of visual acuity served this purpose well, for with it, it was possible to control the amount of light both at the target and in the surround.

Tolerance to target and surround illumination, or point of onset of photophobia was tested at the fifty centimeter test distance. Three levels of target brightness were considered in testing surround light tolerance to determine the effect, if any, this factor produced. These conformed to the target brightness used for a given day, being either one, twelve, or one hundred foot Lamberts. Target light tolerance was tested in the presence of no surround illumination.

On the basis of work done by Peterson and Simonson (12), who found that in young individuals glare had no effect on accommodation tested under situations where ocular irritation was not present, it was felt that tests conducted at fifty centimeters would be valuable.

A typical test at fifty centimeters was run as follows. If the target brightness for a given day was one foot Lambert, a reading of visual acuity was taken first with zero foot candle surround illumination to obtain a basal visual acuity. A visual acuity reading was defined as the threshold determination recorded when the subject was able to answer correctly to three out of four target presentations. Before further testing, surround tolerance was determined by turning the variac slowly until the subject could no longer "tolerate" the light. Following this, three visual acuity readings were taken at each of the three levels of surround illumination--one hundred, two hundred, and three hundred foot candles with an appropriate light adaptation period of one minute before each reading.

After this, the surround illumination was reduced to zero and again a period of one minute was spent adapting to a standard target brightness of twelve foot Lamberts. Following this the variac was slowly turned up until the level of the target tolerance was determined. The entire test procedure took approximately six minutes, and each subject was tested each hour. Means of hourly readings of the subjects were determined and plotted against time after insertion.

Photophobia, as experienced in subjects wearing contact lenses, apparently can be the result of two factors--ocular irritation and corneal clouding. The causes of ocular irritation may be:

1. Improper fitting of lenses, which causes irritation to the cornea, conjunctiva or lids.

2. Chemical irritation from wetting agents, solution, and unclean lenses.

3. Gaseous irritation from smoke, gunpowder, etc.

4. Irritation from dust and other foreign bodies.

5. Poor tolerance or inadequate adaptation to contact lenses.

When corneal clouding causes a sufficient scattering of light rays entering the eye, there results a veiling glare which produces photophobia.

From the results of this study, it seems apparent that the photophobia resulting from ocular irritation is apt to be produced by light from any source. This type of photophobia is usually accompanied by varying degrees of lacrimation, pain, blepharospasm, and often accommodative spasm (13, 14, 15). The photophobia, secondary to veiling glare at the levels tested and in the presence of the degree of corneal clouding that was found, was seldom severe enough to produce lacrimation, etc. These conditions were prevalent especially in the presence of an extended light source which induced increased scattering. It often was difficult to separate the two primary causes of photophobia and to determine the relative effects of each. Photophobia when present without corneal haze was presumed to be caused by ocular irritation.

SPECTACLES:

At the levels tested for both target brightness (Fig. 30, 32, 34) and surround illumination (Fig. 31, 33, 35), subjects wearing spectacles experienced no photophobia under normal conditions, at climatic extremes, or at a similated high altitude.

The levels of lighting at which this experiment was conducted did not reach the tolerance level when spectacles were worn.

FLUID LENS:

There was a progressive drop in tolerance to surround illumination when fluid lenses were worn (Fig. 36). The different levels produced by varying the target brightness had little apparent effect on tolerance to surround illumination. The slightly higher last point at the end of the graph is due to the readings being taken subsequent to the average removal time. The subjects with the poorest tolerance to light were forced to remove the lenses earlier than normal.

Tolerance to target brightness with zero surround illumination (Fig. 30) showed only slight variation and this only after the fourth hour. This decrease in tolerance was minimal.

Tests for the tolerance to surround illumination in the hot room revealed a more rapid and marked decline than under normal conditions (Fig. 37). The decline in the cold room was not as great (Fig. 37). In the low pressure chamber, the findings were essentially similar to those for the hot room (Fig 35). Target tolerance did not vary appreciably in either the hot or cold rooms (Fig. 32), or in the low pressure chamber (Fig. 34).

Photophobia apparently becomes a problem in wearing the fluid lens. From the time of insertion of the fluid lens, there was a progressive decrease in tolerance to surround illumination, while target tolerance was relatively unaffected at the levels tested. It would appear that there were two prime causes for this decrease in tolerance; first, irritation, and second, veiling glare. The initial photophobia was undoubtedly caused by mechanical irritation or the irritation of the solution used with the lens. While attempt was made always to use a standard 1-1/2% solution of sodium bicarbonate, there was some variation from day to day. If the subjects were careless and failed to cleanse their hands thoroughly, especially after smoking, they experienced more irritation when inserting the lenses. While the initial and occasionally subsequent photophobia might have been associated with the above causes, it did not appear to be the main factor, since there was little variation initially and target tolerance was virtually unaffected.

Veiling glare, therefore, was probably responsible for a considerable amount of the reduced tolerance to light. Holliday (9), Harrison (10), and Crouch (8), all have discussed the effect of veiling glare upon visual acuity, comfort and light adaptation. It was evident that with the progressive development of corneal clouding, tolerance to surround light decreased. The surround, being an extended overall source, produced a marked veiling glare in the presence of corneal haze, which was proportional to the depth of that haze, while the small target light source had little effect until corneal haze was extreme. The effect of the veiling glare was somewhat comparable to night driving with a dirty windshield in the presence of bright lights.

The more marked photophobia, as evidenced in the hot room with the fluid lens, was due to increased mechanical irritation and more rapid development of haze.

DALLOS AND LACRILENS:

Subjects wearing the Dallos and Lacrilens revealed very little variation in tolerance to surround illumination at the various target levels tested during the fourteen hour experimental runs and under the various climatic and atmospheric extremes (Fig. 31, 33, 35). Photophobia was not observed in the target tolerance testing under normal and extreme conditions (Fig. 30, 32, 34). The slight variation in surround tolerance seen under normal conditions (Fig. 31) with the Dallos lens was due to one subject whose limbal vent occasionally became blocked with mucus after long hours of wear, while that seen with the Lacrilens (Fig. 31) was due to one subject who experienced some mechanical irritation.

Since the Dallos lens and the Lacrilens were comfortably worn under these test conditions by most subjects and since there was no evidence of corneal haze, mechanical irritation, or veiling glare, photophobia did not develop. The one subject who had mechanical irritation with the Lacrilens developed photophobia and the one subject with the Dallos lens whose cornea was improperly aerated because of a mucus block probably developed some corneal haze and subsequnet photophobia.

TUOHY LENS:

The tolerance to surround illumination with the Tuohy lens revealed marked photophobia in Group A (Fig. 38). These subjects experienced considerable discomfort during this test. It appears from this graph that the tolerance to surround illumination was greater at the higher levels of target brightness. However, examination of individual readings did not bear this out. The photophobia was progressive with wearing time. Group A tolerance to target brightness was reduced somewhat (Fig. 30), but not to the extent noted in relation to surround (Fig. 38).

In Group B, the initial drop in surround tolerance as seen in Fig. 38 was the result of two phenomena. Some subjects who wore the lenses more than four hours showed a progressive decrease in tolerance until the lenses were removed. A few subjects had photophobia shortly after inserting the lenses, which after a few hours subsided and did not recur throughout the wearing period. There was close association between decrease in surround tolerance and reduction of visual acuity. There was a lack of association of tolerance to surround and level of target brightness. There was no variation in target tolerance in Group B (Fig. 30).

The findings in the hot room followed a similar pattern, but were slightly accentuated (Fig. 39, 32). The tolerance to surround (Fig. 39) and target lighting (Fig. 32) was good in the cold room in both Group A and Group B. In the low pressure chamber (Fig. 34, 35), the findings were essentially the same as under normal conditions for Group B. The findings from Group A are not shown on the graphs since data were insufficient and inconsistent due to the extreme discomfort of the subjects during this test.

The tolerance to light with the Tuohy lens was poor. This was essentially due to ocular discomfort which was the result of mechanical irritation or poor individual tolerance to the lens. With rare exception, even the subjects who best tolerated these lenses experienced some discomfort, especially in the first few hours of wearing. These difficulties were exaggerated in the hot room and somewhat alleviated in the cold room, while the low pressure findings were similar to those under normal conditions.

5. Dark adaptation

It was hypothesized that the corneal haze would act as a light filter, and thus would increase the time necessary for dark adaptation. A Telesilhouette Self-Illumination Radium Plaque Adaptometer (Navy Issue) was used for testing dark adaptation. Light adaptation at one hundred foot candles surround illumination and one hundred foot Lamberts target brightness for one minute was accomplished before the subject entered the darkened room. When the subject, seated five feet from the instrument, responded correctly to three out of four rotations of a target on the radium plaque, viewed through a filter, he was considered dark adapted. Means of hourly readings were taken.

With the exception of the fluid lens, there was no consistent variation in dark adaptation during a period of eight hours with the other contact lenses or spectacles (Fig. 40). It is apparent from this graph that shortly after the appearance of the chromatic halo with the fluid lens, the time required to dark adapt was increased.

Dark adaptation was not appreciably affected by the wearing of contact lenses unless a corneal haze developed. The probable explanation for this phenomenon is that the corneal haze tended to act as a filter which necessitated a more complete dark adaptation to perceive a given amount of light. There appeared to be a proportional relationship between the depth of haze and dark adaptation time.

6. <u>Muscle balance</u>

Although accommodation and convergence readings were taken during the preliminary manifest refractions on the subjects, it was decided to study changes in phoria with contact lens wear. Alpern (16, 17) and Firestone and Gaynes (18) have done extensive work in this field. The present study afforded an opportunity to check their findings for the particular lenses used. An American Optical Company Phorometer was used, and the halo identification light at twenty feet served as the light source. Horizontal phoria was taken by using rotary prisms and vertical phoria by using a Maddox rod. The subjects were taught the method and theory of the phoria tests, and after suitable practice took hourly readings before insertion and during the experimental presentation. This was done three times during each test cycle. Since the volume of testing was so great, the subjects were paired off at the beginning of the experiment and instructed to take readings on each other throughout the five cycles. Thus, each subject was tested by the same man in all tests each day. Means of hourly readings are presented.

Phorias tested under normal conditions revealed essentially no unusual variation during the time the lenses were worn (Fig. 41). The only possible exception was that with the corneal lens in those individuals whose tolerance was poor. There seemed to be a slight shift to esophoria and left hyperphoria in this group of subjects. Phorias tested in the low pressure chamber (Fig. 42) were much more variable and erratic, and did not follow a consistent pattern. It was impractical to attempt this test in the hot or the cold room.

Alpern (16, 17), and Firestone and Gaynes (18) reported significant variations in phoria or fusional convergence in contact lens wearers. This was not born out by the testing as conducted in this laboratory. The unusual esophoria and left hyperphoria seen in Fig. 41 and 42 could be attributed largely to two subjects, one of whom had an esophoria that ranged from ten to fifteen diopters under normal conditions and the other who had a left hyperphoria of five diopters which did not vary. Since these subjects manifested no difficulty in fusing, it was not felt that there was sufficient justification to drop them from this test.

The Tuohy Group A subjects revealed the widest variation. These subjects experienced considerable discomfort from the lenses, and the general increase in esophoria might well have been attributable to accommodative spasm. The variation in vertical phoria was largely attributable to the one individual with high hyperphoria, since he experienced difficulty in maintaining fusion with this lens. The Tuohy Group F readings tended to be lower than the average for the other lenses. This could be accounted for by the fact that the two men with extremely high phorias were always represented in Group A.

The erratic effects noted in the low pressure chamber might have been attributable to hypoxia due to removal of the masks for excessively long periods of time while doing the tests. MacFarland (19) and Weaver (20) found that inherent weakness of extraocular muscles became more apparent in conditions of hypoxia. There seemed to be no uniform pattern of effects that could be attributable to the lenses. Here again the two subjects with the excessive phoria tended to exaggerate the tendency to greater esophoria and left hyperphoria.

7. Entoptic fields

Entoptic field patterns are essentially shadows of opaque or semi-opaque objects in the ocular media. This phenomenon may be seen if parallel light passes through the eye. In order to test this, a ten power microscope eyepiece is employed. The rear focal point of the eyepiece falls approximately at the anterior focal point of the eye, thus the light reaching the retina will be parallel and an entoptic field may be viewed. The limit of this field is the inner border of the iris which acts as the aperture stop for this system. Finkelstein (2) found consistent changes in the pattern of the entoptic field with the development of haze and halo in wearers of the fluid lenses. It was decided to determine if entoptic field changes were developed by the wearers of all contact lenses, or if these changes were dependent only upon the corneal edema which developed concurrently with haze. Readings were taken hourly after the appearance of entoptic field changes.

With the fluid lens, there was a gradually progressive entoptic field change. The individual findings were quite consistent from day to day under normal conditions. Under special conditions, there was no consistent variation from normal.

There were only occasional entoptic field changes noted in scattered instances with the other lenses. Some of these findings were progressive and others appeared only for transient periods.

The findings with the fluid lens were essentially in agreement with those of Finkelstein. He did not report any entoptic field changes with the Dallos or corneal lenses. In this study the instances where such changes occurred with the Dallos, Tuohy and Lacrilens were scattered and too inconsistent to merit further analysis.

8. Color vision

All subjects were first tested for color vision by means of the American Optical Company Pseudo-Isochromatic Plates. Nine of the ten subjects qualified as having normal color vision and hence were eligible for further testing on a Bausch and Lomb Anomaloscope.* The anomaloscope consists of two adjacent comparison fields. The top field is yellow and the intensity of this is variable. The lower varies from red through yellow to green. The subject makes a match of yellows. For example, if more red than normal is required, a red deficiency to that amount is present. Four readings were taken each hour and the means of each set were determined.

Finkelstein (2) found that there was a shift toward the green which was due to diffraction and scattering when haze and halo developed. This study sought to confirm Finkelstein's findings, to determine if this shift was evident with any other lenses and to discover if there were any other shifts in color perception due to other reasons.

The findings in this study were essentially in agreement with those of Finkelstein. With the development of corneal haze and the resultant corneal scatter as seen with the fluid lens, there was a slight tendency to green deficiency as manifested by the anomaloscope (Fig. 43). Other than this there were no consistent significant changes in red-green color perception. This held true in the hot and cold rooms and in the low pressure chamber.

9. Depth perception

Tests of binocular stereoptic acuity and spatial localization were conducted jointly with the Department of Psychology. A preliminary report (21) dealing with the Dallos lens, the fluid lens and

*The authors wish to thank Dr. Gertrude Rand of the Eye Institute of Presbyterian Hospital, New York City, for the use of a Bausch and Lomb Anomaloscope.

spectacles has been published, and a final report (22) will be published shortly.

Differences in performance did exist between individuals and contact lenses and spectacles. However, there was no set pattern of variation for each lens.

Neither contact lenses nor spectacles produced a consistent variation in binocular stereoptic acuity or spatial localization; nor did one prove superior. In light of the fact that there were individual differences among the lenses worn, it is deemed advisable that personnel performing fine ranging tasks determine their normal binocular acuity and spatial localization for the particular lenses they may be wearing.

10. Clinical appearance

Throughout the entire experimental period, continued observations were made on the clinical appearance of the cornea and anterior segment. A Bausch and Lomb Universal Slit lamp with high and low power objectives was used for these observations.

As a rule, when the lenses were worn comfortably, there was little evidence of ocular irritation. It generally was true throughout the experimental period that the Dallos lens and the Lacrilens produced little irritation, although there were exceptions. Rarely did the cornea stain with fluorescein even after extended wearing periods with these lenses. Mucus formation with these lenses was observed occasionally. When excessive amounts collected under the lens, it frequently was necessary to remove and clean the lenses.

After extended wearing periods with the fluid lens, the cornea became hazed and edematous. Frequently the conjunctiva became injected, especially in the circum-corneal region. This was not necessarily accompanied by subjective discomfort. There was no corneal staining.

It was frequently observed after removal of the Tuohy lenses, and especially in the presence of subjective discomfort, that the corneal epithelium revealed stippling which stained superficially with fluorescein. The location of the stippled areas was scattered. Conjunctival injection, tearing, photophobia, and blepharospasm were observed frequently while the lenses were being worn.

While smoke and other chemical irritants produced the usual untoward effects in subjects wearing spectacles, these effects were greatly intensified in the presence of any of the contact lenses. This irritation appeared to be somewhat less marked with the fluid lenses than with the other types. In the presence of excessive amounts of dust, particles were frequently seen under the Dallos, Lacrilens, and Tuohy lenses.

The Dallos and the Lacrilens, as a rule, produced minimal objective ocular change. The fluid lens produced progressive conjunctival and corneal change. The frequency with which stippling of the corneal epithelium was observed would indicate that the physiological tolerance was poor for the Tuohy lens and that the subjective symptoms were secondary to definite corneal injury. These effects were probably mechanical and could have been the result of excessive friction between the lens and cornea. Whether this was due to intrinsic lens design or poor fit was undetermined. Some of the discomfort, especially in the adaptation period, was due to irritation of the lids as they constantly rubbed over the beveled edge of the lens. This also may have accounted for the somewhat more extended adaptation period for the Tuohy lens.

The tolerance to any ocular irritant was greatly reduced in the presence of any of the contact lenses tested. This irritation was less marked with the fluid lens where the cornea was protected by the lens and fluid, leaving only the lids exposed to the irritant.

11. Visual field

Peripheral fields of vision were tested on a Ferree-Rand Perimeter, while spectacles and contact lenses were worn. A two millimeter white test object was used.

The peripheral field of vision was found to be very slightly larger when contact lenses rather than spectacles were worn. The increase in size did not exceed 3% with any of the lenses.

While the peripheral visual field was not appreciably increased when contact lenses are worn, the effective scope was greatly improved. The lenses rotate with the eye and there were no frames to limit the field. The annoying effects of aberration due to high refractive errors were not found.

B. Special Duties

1. Clerical duty

Subjective reports of the individuals stated their reaction to contact lenses and spectacles while they were performing the various clerical duties associated with their laboratory work.

Extended periods of clerical work or close work in general caused mixed reactions among the subjects and the different lenses. The only variation that was at all consistent was burning and asthenopia after a few hours of close work by a few subjects. In the presence of ocular irritation, clerical work was correspondingly more difficult.

One possible explanation for the burning sensation after prolonged close work is that with concentration, the blink reflex that is already reduced when contact lenses are worn, is further decreased. This allows the lens to dry and when the lid closes over the dried lens, it becomes irritated.

2. Hot room

Testing in the hot room was conducted with the temperature at +120° Fahrenheit and relative humidity of 35%. The subjects remained in this room for eight hours with food and cool drinks supplied at regular intervals. Time for development of halos was determined for the five test cycles. It was possible to take the testing equipment into the hot room for two cycles, and readings were taken for color, entoptic field, visual acuity and photophobia, with target brightness at twelve foot Lamberts. In the other cycles, readings were taken after emerging from the hot room. Subjective reports were submitted.

In general, the subjects reported greater discomfort with all lenses in the hot room. Symptoms of burning, tearing, and photophobia were common. Halos, when present, appeared earlier (Fig. 34). Perspiration caused soiling of spectacle lenses.

The explanation for the reduced tolerance to contact lenses was not clear. It might be explained that heat caused vasodilation and congestion of the conjunctiva which interfered with the fit of the lens. Also, the generalized discomfort at 120° Fahrenheit lowered the morale and increased the irritability of the person as a whole.

3. Cold room

Testing in the cold room was done at an ambient temperature of -40° Fahrenheit, with and without wind. The subjects remained in this room the entire eight hour period of testing, with food and hot coffee supplied to them at regular periods. The only instrumentation kept in the test room was the microscope illuminator so that halo time might be noted. A reading was taken on the anomaloscope and phorometer for each of the test subjects immediately after he emerged from the cold room. Visual acuity and photophobia were tested with the target brightness at twelve foot Lamberts. Readings were taken for the five test cycles on halo time and for three cycles on all other testing. Subjective reports were submitted.

The findings in the cold room were, in many respects, the opposite of those in the hot room. Ocular irritation was in general greatly reduced with all lenses. Those wearing the fluid lens found that halos appeared later than under normal conditions (Fig. 5). Visual acuity in general was better. Spectacles tended to frost over in the test chamber, and when the subject left the cold room and emerged into the warmer atmosphere, his spectacles became clouded. Wind seemed to have little specific effect.

General vaso-constriction might have been responsible for the greater wearing comfort in the cold room.

4. Low pressure chamber

Tests were conducted at the Aero-Medical Research Laboratory*, Wright-Patterson Air Force Base, Dayton, Ohio, to determine the effect of reduction of atmospheric oxygen on the eyes. Smelser (1) found this to be one of the causes of corneal haze. Thus the question was whether the moderate ocular anoxia experienced at high altitude flying would influence the corneal changes. Another consideration was the possible effect of rapid changes of altitude. Possible expulsion of the lens, change in bubble size with consequent decrease in visual acuity, and formation of bubbles under the fluid lens were also considered.

The testing was divided into two phases; - sudden decompression and an extended period at a simulated altitude of 20,000 feet.

---

*The use of the facilities and assistance of the personnel of the Aero-Medical Research Laboratory was greatly appreciated.

Subjective reports were made after completion of the sudden decompression test. The test was as follows: ascent to eight thousand feet in one-half minute followed by explosive decompression from eight thousand feet to twenty-five thousand feet in two seconds. This altitude was maintained for one minute, then gradual descent was made to ground level in from three to five minutes. Oxygen masks not covering the eyes were worn.

The lenses were worn for an extended period at twenty thousand feet. The subjects stayed in the low pressure chamber for eight hours while wearing A-14 and A-13-A oxygen masks with microphone and headsets. The following tests were conducted for three of the test cycles: color vision, phoria, halo time, entoptic field, and a visual acuity and photophobia series with twelve foot Lamberts of target brightness. Subjective findings were recorded. Food and beverages were provided periodically during the eight hours.

Essentially, there was not a great deal of variation caused by sudden decompression. A few subjects reported an increase in bubble size, which was transient.

Testing at the simulated high altitude apparently did not cause marked variations in any of the results. Those wearing the spectacles experienced discomfort from the tight head gear that pressed upon the spectacle frames.

Except for the occasional variation in bubble size, testing at low pressure revealed nothing unusual. It had been anticipated that direct exposure of the eyes to the reduced oxygen pressure at high altitudes might have produced some corneal changes. Although this was known not to occur in individuals who were not wearing contact lenses, it was theorized that with the additional reduction in aeration to the cornea inherent with wearing contact lenses, changes might have taken place. These did not occur.

Spectacles worn under headgear of any nature proved, in most cases, to be uncomfortable, especially when long test periods were conducted.

These effects were compared with findings at the relatively normal altitude of seven hundred and fifty-three feet at Fort Knox, Kentucky.

5. Protective factors

Contact lenses, by their position in the eye, offer a certain amount of protection. Small foreign bodies, mud, rain, etc., are kept from the cornea by the lenses. The protective element was well demonstrated on two occasions. One subject, while crawling through a barbed wire entanglement on the infiltration course, was struck in the eye with a barb, but the cornea was protected. Another subject was struck in the eye with a buckle, and although his plastic lens was cracked, his eye was not injured.

Plastic lenses offer partial protection against ultra-violet rays.* Light rays of approximately 4000A and below become dangerous to the eye. Methyl methacrylate, the plastic used in contact lenses, filters rays at a wave length of 3100A, and below 2866A there is no apparent transmission.

Glass lenses filter essentially all damaging rays in the ultra-violet range. The glass contact lens, in covering the entire globe, protects against radiation from all directions. Spectacles protect only the areas they shield.

Both the plastic and glass lenses offer protection against alpha radiation.** Protection against beta radiation is variable. It is dependent upon the energy of the beta particles and the thickness of the lens. Although glass gives somewhat greater protection than plastic, due to the relatively incomplete coverage by spectacle lenses, protection is limited.

Virtually no protection is offered against gamma and x-radiation by either contact lenses or spectacles.

C. Field Studies

In the field studies, an attempt was made to test the effects of as many conditions as possible with which a member of the Armed Forces may be confronted.

*Mr. Raymond R. Heer, Jr., of this laboratory was very kind in offering his assistance on this topic.

**Dr. Adolph Krebs of this laboratory was very kind in offering his assistance on this topic.

1. Service firing*

Service firing, or tank gunnery, included the firing of a 75 mm. gun and 50 and 30 caliber machine guns at both stationary and moving targets. This test was conducted to determine the effect of the lenses on sighting and firing, as well as the effect of the concussion upon the lenses. As a further test of concussion, on one occasion the men were placed in close approximation to 105 mm. howitzers that were being fired.

DALLOS LENS:

Six out of seven subjects had no adverse effects. One subject had to remove one lens because dirt became lodged between it and the cornea.

FLUID LENS:

Of eight subjects, four had no significant complaints. Two were irritated by powder fumes, and two complained of photophobia and burning. With the development of haze two had difficulty sighting on targets.

LACRILENS:

Three of eight subjects experienced no difficulty. Three complained of burning from powder fumes. One found dust and wind irritating, while one had some photophobia.

TUOHY LENS:

All of the eight subjects experienced discomfort caused by the fumes from the gun powder. Two subjects had their lenses dislodged by concussion and the lenses were lost in the field.

SPECTACLES:

The six subjects wearing spectacles experienced difficulty in using the sighting device due to its construction. Rain spotted the lenses of one subject, thus interfering with his vision.

*ATP 17-600-1A Training Memorandum 40-18T(S) and 40-19T(S), Hq, 3rd Armored Division, Fort Knox, Kentucky. 14 January 1952

In service firing, the Lacrilens and Dallos lens proved superior to the Fluid and Tuohy lenses. Powder fumes proved irritating to all.

2. Confidence course*

The confidence course, formerly known as the obstacle course, consisted of a series of hazards which were meant to incorporate many of the essentials of physical training. It included physical activity such as climbing, swinging, jumping, balancing, etc.

DALLOS LENS:

Five subjects wearing the Dallos lens reported the lenses to be very satisfactory. No adverse effects were noted.

FLUID LENS:

Of six subjects tested, three reported no adverse effects. Two reported annoying photophobia and one complained that stationary objects seemed to jump and move at times when the subject was experiencing excessive activity. No subject reported the appearance of air bubbles as a result of this activity.

LACRILENS:

Of six subjects tested, all had satisfactory reports.

TUOHY LENS:

Of six subjects tested, two reported no adverse effects, four complained of annoying photophobia and general ocular discomfort. The lenses were not dislodged in any case.

SPECTACLES:

Of five subjects tested, no adverse effects were noted, however, special precautions were required to prevent dislodgment of spectacle frames.

On the confidence course, the Dallos and Lacrilens appeared to be superior since no adverse effects were noted while wearing either lens.

---

*ATP 7-600-1, 7-701-1, 17-600-1, 17-601-1, 21-114. Training Memorandum #29T, R, B, L&H, Hq. 3rd Armored Division Fort Knox, Kentucky. 6 December 1951.

3. Browning automatic rifle known distance and transition range firing*

Firing with the Browning Automatic Rifle was included in the studies to determine the effect of greater weapon recoil and rapid fire.

DALLOS LENS:

Three subjects experienced no difficulty firing this weapon. One of these had some mucus formation.

FLUID LENS:

The three subjects that fired had mixed reactions due primarily to photophobia and haze. This was largely dependent upon the length of time that the lenses were worn rather than the actual field test itself.

LACRILENS:

Of five subjects tested, none had any difficulty firing, but two had moderate irritation caused by the lenses.

TUOHY LENS:

Four subjects all complained of photophobia but had no symptoms referable to the firing.

SPECTACLES:

Four subjects had no difficulties.

There seemed to be no difficulties attributable to the firing of the Browning Automatic Rifle in either contact lenses or spectacles.

4. Hand-to-hand combat

Hand-to-hand combat was an exercise where the man was taught offensive and defensive maneuvers with the rifle and bayonet. The results reported here reflect those phases of this training

*ATP 7-600-1, Training Memorandum #31L and change #1, Hq. 3rd Armored Division, Fort Knox, Kentucky. 7 February 1952.

where the trainee learned the basic stances and positions used in bayonet fighting.

DALLOS, FLUID, AND LACRILENS:

Two subjects with each of these lenses had no adverse comments.

TOUHY LENS:

One of two subjects reported photophobia, while the other found that on sudden whirling there was a momentary blurring of vision.

SPECTACLES:

One subject had no adverse comment.

This exercise was dropped from the program after the first series since it was felt that little knowledge was gained from the rather passive activity of this portion of the training.

5. Individual tactical training (night)*

This was a company level night tactical training problem which necessitated movement through a wooded terrain to establish advanced posts and a combat line. Blank cartridges and carbine-launched grenade flares were fired.

DALLOS LENS:

Five subjects had no adverse comments.

FLUID LENS:

Of five subjects, two experienced little difficulty. Two complained of difficulty in seeing, and of photophobia as a result of haze. The fifth subject complained of a burning sensation.

LACRILENS:

Six subjects had no adverse comments.

ATP 7-600-1, 7-60-1, 17-600-1A, 17-600-1B, 17-601-1, 21-114. Training Memorandum #35B, #35C, 47A, 47C, and change #1. Hq. 3rd Armored Division, Fort Knox, Kentucky. 25 March 1952.

TUOHY LENS:

Six subjects had no adverse comments. One subject found that while lying prone, upward version of his eyes was difficult.

SPECTACLES:

No adverse comment was noted by the six subjects.

Most subjects did comparatively well on the problem, which was in keeping with the general findings that subdued illumination and cool outside air added to the comfort of those wearing contact lenses. (Haze lowered the visual acuity of fluid lens wearers.)

6. M1 Rifle known distance and assault and transition firing*

Known distance range firing of the U.S. rifle 30 caliber M1 included firing at fixed targets from the standing, kneeling, squatting and prone positions.

The transition phase of the training included firing the rifle at fleeting targets from behind various protective enclosures. This required practice in all of the basic positions. In firing the assault range, the trainee walked up a path firing instantaneously at fleeting targets as he moved.

DALLOS LENS:

Of five subjects, three reported no difficulty. Two complained that the air bubbles in the lenses interfered somewhat with their ability to sight the rifle.

FLUID LENS:

All of six subjects experienced occasional burning and photophobia. Two of these noted bubble formation during the exercises. One found that corneal haze interfered with his ability to sight the target; while two noted excessive mucus formation.

*ATP 21-114, 7-600-1, 7-601-1, 17-601-1, Training Memorandum 30L, H, R, and 42 basic and change #1, Hq 3d Armored Division, Fort Knox, Kentucky, 19 March 1952.

LACRILENS:

Four of seven subjects experienced no difficulty. Three found that sand blowing in the eyes caused photophobia and discomfort.

TUOHY LENS:

All but one of six subjects experienced photophobia and general ocular discomfort. One subject noted momentary fogging of his lenses after firing, the same subject complained of occasional bubble formation.

SPECTACLES:

Two of six subjects complained that their lenses became spotted with oil during the firing. A third subject had difficulty firing in the rain; another experienced irritation caused by sand blowing in his eyes. One complained that his spectacles were uncomfortable when worn under his helmet. One had no difficulty.

The Dallos and Lacrilens again proved to be more satisfactory in this test. During inclement weather, spectacles had an obvious disadvantage. Hazing of the fluid lens caused difficulty in sighting upon a distant target.

7. Tank driving (day and night)*

These exercises were included to ascertain if there would be any difficulties encountered while driving tanks and other vehicles. Jeeps, half-tracks, and light and medium tanks were driven with and without tanker's protective goggles.

DALLOS LENS:

To five subjects, dust proved to be a serious problem. Three subjects found it necessary to remove and clean their lenses. This situation was alleviated when goggles were worn. Night driving added no significant problems.

*ATP 17-600-1, 17-600-1A, 17-600-1B, Training Memorandum #60R section 2 and 4, 13 November 1951, #60-A sections 3 and 4, 22 January 1952, #60-T sections 2 and 6, 10 May 1952. Hq. 3d Armored Division, Fort Knox, Kentucky

FLUID LENS:

For six subjects, dust again was a problem. One subject found it necessary to remove his lenses. Wind caused a drying of the lens surface which resulted in irritation and photophobia. Wherever haze and halo were present, night driving became hazardous. In one instance, the lenses protected the eyes from flying mud. Goggles again helped alleviate some of the problems.

LACRILENS:

Five of seven subjects had no marked reaction, although dust proved irritating. Two subjects found that dust, exhaust fumes, and jarring aggravated the irritation in their eyes. Night driving added no further problems and goggles eliminated some.

TUOHY LENS:

Six subjects found dust very irritating and they all had to remove the lenses at one time or another during the trials. Goggles offered partial protection from the dust. Exhaust fumes from the tank added to the irritation. One subject had a lens dislodged by the jarring. Night driving added no further problems.

SPECTACLES:

Of six subjects, four reported impairment of vision as a result of mud splattering on the lenses. In one case, the frames were dislodged by the jarring. Goggles fitted poorly over the spectacles and caused discomfort. The goggles did not form a perfect seal, and therefore did not protect the eyes completely from the dust.

Dust presented the major problem, while exhaust fumes, wind, mud and jarring were other pertinent factors. Most of these were alleviated by wearing dust protective goggles. Since these could not be worn with comfort over spectacles, a better combination seemed to be contact lenses plus goggles. Here again the Dallos and Lacrilens with goggles seemed to be superior

8. Infiltration and close combat*

The infiltration course provided mental conditioning for combat by creeping, crawling, and negotiating obstacles under fire. These obstacles included barbed wire entanglements with live machine gun fire directly overhead. Ground detonations in close approximation were added obstacles.

The close combat course was a simulated attack through rough terrain which necessitated running, jumping, climbing, and crawling. Throughout the course there were a number of supposed enemy emplacements toward which the trainee directed M1 rifle fire.

DALLOS LENS:

Of five subjects tested, two had no difficulties. Three of five experienced considerable irritation to their eyes from sand thrown about by the detonations and it was necessary for two of them to remove their lenses before completing the course. One subject was undoubtedly protected by his lenses from probably serious injury to his cornea when a barbed wire struck him in the eye. The concussion from the detonations apparently had little effect.

FLUID LENS:

Two of six subjects reported no difficulty. Three were irritated to varying degrees by the sand. Of these, one found it necessary to remove his lenses. One complained of photophobia. The concussion apparently had no effect and there was no bubble formation.

LACRILENS:

Five of seven subjects had no irritation or other difficulty. Two found the sand irritating. Concussion had no effect.

---

*Infiltration: ATP 21-114, 7-600-1, 7-01-1, 17-600-1, 17-601-1, Training Memorandum #50 and change #1 6 May 1952, Hq 3d Armored Division, Fort Knox, Kentucky.

*Close combat: ATP 21-110N, 7-600, 7-601, 17-600, 17-601, Training Memorandum #1, Hq 3d Armored Division, Fort Knox, Kentucky. 11 June 1951

TUOHY LENS:

Two of six subjects expressed no difficulty as a result of the test. It was necessary for three subjects to remove their lenses due to irritation caused by sand. One subject reported that his lenses became dislodged while crawling on his back under barbed wire. Concussion apparently had little effect.

SPECTACLES:

Of the five subjects participating, only one reported no difficulty. Three complained of impairment of vision caused by mud, dust, and perspiration on the spectacles. One subject reported that his spectacles were dislodged by the barbed wire.

To all subjects wearing contact lenses, dust and sand proved to be a great source of irritation. The ease with which the Tuohy lens could be dislodged from the cornea again proved to be a disadvantage. Spectacles, because of their relatively vulnerable position, were easily soiled, dislodged, or broken under these conditions.

9. Combat in towns*

This exercise was intended to train the individual soldier in the proper method of clearing a village, to fire accurately and quickly at fleeting targets and to work efficiently as a part of a team while surrounded by the noise and hazards of battle. This assault might be considered as a culmination of the varied aspects of basic training and included firing of the M1 rifle while exposed to machine gun fire, detonations, and smoke screens. The soldier had to negotiate a number of physical hazards by climbing, jumping, etc.

DALLOS LENS:

Of five subjects tested, three had no complaints. One subject reported minor irritation from smoke and powder fumes, and one experienced doubling of vision during detonations.

FLUID LENS:

Two of five subjects had no difficulties; while three experienced burning and photophobia.

*ATP 7-600, 7-601, 17-600, 17-601. Training Memorandum #52 L,H,T,R and change #1, Hq 3d Armored Division, Fort Knox, Kentucky. 22 June 1951.

LACRILENS:

Two of seven subjects reported no difficulty. Two found it necessary to remove their lenses because of irritation caused by the smoke grenades. Two subjects reported some photophobia and one complained of haze.

TUOHY LENS:

One of six subjects experienced no discomfort. Three had great discomfort from smoke grenades. Of these one had to remove his lenses. The others complained of varying degrees of burning.

SPECTACLES:

Of five subjects, one had no referable complaints. Three complained of smearing of their glasses with perspiration, mud, dirt, and water from the detonations. One complained of irritation from the smoke.

Smoke grenades appeared to be a source of irritation to all subjects. The Dallos and Lacrilens again appeared to be more satisfactory. The danger of spotting, dislodgement and breakage of spectacles under such conditions made them impractical.

10. Gas masks

Spectacles always have proven to be a problem when a gas mask is worn because of the difficulty in obtaining an atmospheric seal over the spectacle frame. Therefore, if contact lenses could be worn comfortably in the gas mask instead of the special lens inserts that are now required, the problem would be simplified.

DALLOS LENS:

Only two of nine subjects tested could comfortably wear the lenses with the gas mask. Five experienced discomfort as the result of the nosepiece on the mask causing pressure on the lower lid. Another complaint was that exhaled breath which circulated around the eyes caused irritation. The wearing time was rather limited.

FLUID LENS:

Only two of nine subjects were able to wear the fluid lens and mask with comfort. The remaining seven subjects had considerable discomfort resulting from the pressure of the nosepiece of the mask on the lower lid. Here again the wearing time was rather limited.

LACRILENS:

Two of eleven subjects were relatively comfortable with the Lacrilens and gas mask. Two reported slight burning. The remainder complained of burning and photophobia from pressure and heat. Only short wearing time was possible.

TUOHY LENS:

Of ten subjects, one reported relative comfort. The remainder complained that the pressure from the mask and the exhaled breath caused irritation. The wearing time was limited.

SPECTACLES:

A tight seal of the gas mask over spectacles was impossible. There also was considerable discomfort from pressure on the frames. Special lens inserts are required in the masks for satisfactory use.

The same general complaint seemed to hold throughout these tests, the nose piece of the gas mask caused pressure against the cheeks and lower lids, which in turn pressed against the lenses and caused irritation. Exhaled air also proved irritating. Apparently contact lenses do not obviate the problem of the gas mask and the soldier with refractive error. It is quite probable however, that a slight modification of the gas mask would alleviate the pressure against the lower lid, which proved to be the chief source of irritation in the contact lens wearer.

II. <u>Swimming</u>

This test was to determine the effect on contact lens wearers while swimming, being submerged under water, and diving.

DALLOS LENS:

Five of nine subjects reported no difficulty. Three complained of transient haze and halo which presumedly was due to the accumulation under the lens of water which was not isotonic with the tears. This condition cleared shortly after leaving the water. One complained of slight photophobia.

FLUID LENS:

Six of the ten subjects reported no adverse effects. Several reported excellent underwater vision. Three subjects complained of slight burning and irritation, presumedly due to the chlorine in the water. One complained of extreme photophobia and burning.

LACRILENS:

Four subjects out of ten had no complaints. Two reported transient haze and halo. Four reported increased burning and irritation from the chlorine.

TUOHY LENS:

Three of the ten subjects had no complaints. Five subjects complained of photophobia and three reported that the lenses were displaced after submersion with the eyes open. One complained of severe burning and tearing. No haze or halo was noted.

SPECTACLES:

Spectacles are impractical for swimming for obvious reasons.

The fluid lens seemingly proved the most satisfactory in this test. Chlorinated water caused some general discomfort by irritating the eyes. The disadvantage that became apparent in the ventilated lens was the appearance of haze and halo, probably because of the accumulation of water under the lens. The danger of displacement and loss of the corneal lens was ever present.

12. Kitchen police

The subjects performed the routine duty of kitchen police to determine whether or not there would be adverse effects while working at stoves, steam tables and dish washing.

DALLOS LENS:

Of five subjects, two experienced no difficulties. One reported doubling of vision, another mucus formation, and the last frothing.

FLUID LENS:

Six subjects reported varying degrees of discomfort. Two found that steam caused burning and discomfort, while haze and chromatic halo were annoying to three subjects. The sixth subject complained of bubbling and that the surfaces of the lenses dried thus causing irritation.

LACRILENS:

Of seven subjects, five reported no adverse effects. Two experienced burning and doubling of vision.

TUOHY LENS:

Six subjects all found that heat and steam caused burning, tearing, and irritation.

SPECTACLES:

Of six subjects, all but one experienced spotting and fogging of his lenses in the presence of steam.

Contact lenses appeared to be superior to spectacles, although heat and steam did accentuate the irritation caused by contact lenses.

13. Guard duty

The men stood routine watch, two hours on and four hours off, for twenty-four hours. They wore the lenses while on duty, but were allowed to remove them if they so desired when not standing guard.

DALLOS LENS:

Five subjects had no serious complaints. Two experienced a slight burning sensation in the eyes and one other complained of the formation of mucus under his lenses.

FLUID LENS:

Six subjects all reported increasing irritation caused by the repeated insertion and removal of the lenses. One reported photophobia. The lenses were not worn long enough for corneal haze to become a factor.

LACRILENS:

Of seven subjects, five reported no difficulty. One complained of photophobia and one had irritation from the repeated re-insertion of the lenses.

TUOHY LENS:

Six subjects were tested and of these, four complained of increasing irritation upon each successive re-insertion of the lenses. This was especially evident when the lenses were inserted immediately after waking. One complained of photophobia during the day, but was comfortable during the night watch. One subject was comfortable in the cool outdoor air, but experienced difficulty upon entering heated buildings.

SPECTACLES:

Six subjects had no adverse comments.

Repeated insertion and removal of any contact lens caused irritation to the wearers. This was less apparent with the Dallos and Lacrilens, and more noticeable with the fluid and the Tuohy lens. Contact lenses are not recommended for wear while sleeping as they produce irritation and hazing of vision. Spectacles apparently are advantageous to the guard except under certain conditions of adverse weather such as rain, extreme cold, and snow.

14. Parachute jumping*

Wearing a parachute harness, the subjects jumped from a thirty-four foot mock-up tower and experienced a free fall of approximately twelve feet, after which their descent was broken with considerable force as the risers took up the slack in their harness. They were then guided to earth by gradual descent on a cable (23).

DALLOS LENS:

There were no adverse effects noted by five subjects.

FLUID LENS:

There were no adverse effects noted by six subjects. No air bubbles were produced by the jar.

LACRILENS:

No adverse effects were noted by six subjects. One subject, while removing the harness, was struck in the eye by a buckle, and

*This test was performed through the cooperation of the G3 staff section of the 11th Airborne Division at Fort Campbell, Kentucky noticed afterward when removing the lens that it was cracked. This was undoubtedly the result of the blow, and may have protected the eye from serious damage.

TUOHY LENS.

No adverse effects were noted by eight subjects. None of the lenses were displaced from the cornea.

SPECTACLES:

No adverse effects were noted by five subjects, although special precautions had to be taken to prevent dislodgment of the spectacle frames.

No adverse effects were noted with any of the contact lenses. No one lens appeared to be superior in this test. Special precautions were required for spectacles.

IV. GENERAL DISCUSSION AND CONCLUSIONS

A. Advantages of Contact Lenses

Judging from the studies conducted at this laboratory, the performance of contact lenses was for the most part satisfactory. There are, of course, certain drawbacks and disadvantages, just as there are with spectacles. It also is apparent that there is wide variation in performance of the different types of contact lenses.

Contact lenses offer numerous advantages over spectacles to the military. One of the foremost of these is their performance in inclement weather. Rain, snow, mud, etc., which may interfere with vision in those wearing spectacles, cease to be a problem when contact lenses are worn. In extreme cold, spectacle lenses often frost over, and steam up when passing from cold to warm atmosphere. In extreme heat, spectacles become spotted with perspiration, but this does not occur with contact lenses. Most head gear and sighting devices are so constructed that they are not completely adaptable to the individual needs of the spectacle wearer. The gas mask always has presented a problem; special lens inserts are required for individuals requiring visual correction. These problems are for the most part alleviated if contact lenses are substituted. However, the gas mask in its present construction cannot be comfortably tolerated for extended periods by most individuals wearing contact lenses. The mask creates an upward pressure on the lower lids which in turn press upon the contact lenses and creates ocular irritation. Modification of the construction of the gas mask might alleviate this problem.

The advantage of the contact lens in swimming is obvious since spectacles cannot be worn.

In field requirements, where the individual may undergo extreme physical activity, jolting, jarring, and exposure to varied material obstacles, spectacles are at a disadvantage because of their vulnerable position. They are easily dislodged and broken. Contact lenses not only temper these problems, they also offer further protection to the eye. They also reduce the mental concern that the spectacle wearer naturally exhibits in the face of physical obstacles.

In the presence of bright light, there may be reflections from the anterior surface of spectacle lenses which may reveal hidden positions to the enemy. This does not occur with contact lenses.

The protection that contact lenses offer to the eye cannot be overlooked. Not only do they protect against foreign bodies and direct trauma, they also proffer varying degrees of protection against harmful radiation. This variation is dependent partly upon the material used in the fabrication of the contact lenses.

Visual acuity in certain pathological conditions of the cornea, such as keratoconus, irregular astigmatism, etc., is much greater with contact lenses than with spectacles since they essentially form a new corneal surface.

The visual limitations that spectacle frames create and the aberrations existing in high power lenses are eliminated when contact lenses are employed.

Generally speaking, the advantages offered by contact lenses to the military are most pronounced for the field soldier.

B. Disadvantages of Contact Lenses

The most outstanding disadvantages of contact lenses at the present time are the cost, the time, and the skill required for fitting. These limitations stem from the necessity for individual processing that the current techniques require. It is anticipated that, in view of constant efforts of the manufacturers, techniques will continue to improve with time. The time required for adaptation varies with the individual and the lens being worn.

The necessity for accessory fluids associated with contact lenses is another problem. Although the newer types of fluidless lenses have eliminated the problem of contact lens fluid, a wetting agent still is required with the plastic lens. Glass lenses do not require the use of wetting agents. As plastic lenses are worn, they become less difficult to wet. The solutions used of course should be kept relatively sterile and both the lenses and hands of the individual wearer must be clean at the time of insertion. This might present a serious problem in the field. Although some fitters recommend saliva as a wetting agent, the potential dangers of infection hardly warrant its use.

Because of the small size of contact lenses, they are easily lost, or might conceivably be misplaced by the individual seeking to avoid responsibility. The plastic lens is relatively unbreakable, but the glass lens might easily be broken in handling. There is relatively little danger of breakage of the lenses while being worn, but if they should be broken there might well be serious damage to the eye. The effects of ocular irritants are intensified when contact lenses are worn. Irritating gases, smoke, dust, and even light tend to produce greater irritation than normal, especially if the lenses themselves are at all uncomfortable.

While infections of the eye were rarely encountered during the experimental trials reported here, contact lenses present a potential source of ocular infection.

Duplication of the lenses presents a variable problem that depends upon the manufacturers technique.

These disadvantages are of varying importance depending mainly upon the type of lens and the situation that confronts the individual. It may be said that contact lenses cannot be fitted to any individual who does not have motivation or a desire to wear the lenses. If this is lacking, the individual may in innumerable ways foil the fitter, retard adaptation, and dispose of or mutilate the lenses. Thus it may be hypothesized that many personnel might object to being fitted if as a result of adequate fitting they were to be transferred from a relatively protected job to battlefield duty.

C. Discussion of the Contact Lenses Tested

When the four contact lenses that were studied in this experiment are compared, it becomes quite evident that the performance of two was far superior. Each lens has its own place and must be considered for its relative value. There are instances where one lens alone may be superior to the others, but in the overall analysis of the results of the present trials, the Dallos and Lacrilens proved superior.

1. Fluid lens

The advantages of the fluid lens are:

Relative ease of fitting.
Short period of adaptation.
Less susceptible to external irritants.
Good while swimming.
Preferable with corneal pathology.
Relatively unbreakable.
Protects against foreign bodies.

The disadvantages of the fluid lens are:

The development of progressive corneal clouding and edema produce:

a. Hazy or fogged subjective vision.
b. Chromatic halo about lights.
c. Drop in visual acuity, marked.
d. Photophobia.
e. Increased dark adaptation period.
f. Development of entoptic field changes.
g. Limited practical wearing time.

Only limited protection against radiation.
Requires contact lens fluid as well as a wetting agent.
Period of poor vision after removal.
Plastic becomes scratched after use.

It was felt that with the fluid lens the disadvantages far outweighed the advantages, thus making them of limited practical use.

2. Corneal lens

Advantages of the Tuohy corneal lens are:

Relative ease of fitting and reduplication.
Relatively unbreakable.
Rare development of corneal clouding and edema.
Only solution necessary is wetting agent.
Extended wearing time when lenses comfortably tolerated.
Corneal protection from foreign bodies.

Disadvantages of the Tuohy corneal lens are:

Long period of adaptation required.
Jolts and jars tend to displace the lens.
Small size lens is easily lost, especially while swimming.
Left and right lens easily confused.
Ocular irritants result in exaggerated discomfort.
Produces frequent corneal injury which results in:
   a. Drop in visual acuity.
   b. Extreme photophobia.
   c. Poor fusion.
Limits wearing time and individual efficiency.
Only limited protection against radiation.
Plastic becomes scratched with use.
Produces lid irritation.

To evaluate the Tuohy corneal lens presents a difficult problem. Since the quality of the fit may be the cause of the frequent corneal injury that was observed, it was decided to ignore this and judge the lens on its overall performance. The mere fact that this lens is so small and easily dislodged and lost makes it impractical for general field use by the Armed Forces. The disadvantages seemed to outweigh the advantages.

3. Lacrilens

Advantages of the Lacrilens are:

Short period of adaptation.
Good while swimming.
Relatively unbreakable.

Rare development of corneal clouding and edema
Only solution required is a wetting agent.
Difficult to dislodge.
Extended wearing period with comfort.
Photophobia is not marked and vision is good.
Protection from foreign bodies.

Disadvantages of the Lacrilens are:

Long and difficult fitting period required.
Reduplication difficult.
Ocular irritants result in discomfort.
Plastic becomes scratched with use.
Only limited protection against harmful radiation.

The main disadvantages of the Lacrilens involve the fitting of the lens. It is felt that in time and with continued study, these will be overcome. Thus this lens proved to be superior.

4. Dallos lens

Advantages of the Dallos lens are:

Short period of adaptation.
Good while swimming.
Rare development of corneal clouding and edema.
No solution is required.
Difficult to dislodge.
Extended wearing period with comfort.
Photophobia is not marked and vision is good.
Good protection against most harmful radiation.
Retains polish of surfaces.
Easily reduplicated.
Protection from foreign bodies.

Disadvantages of the Dallos lens are:

Easily broken.
Extremely long and difficult fitting period.
Ocular irritants result in discomfort.
Mucus frequently plugs vent.

The main disadvantages of the Dallos lens are the fitting time and the ease with which the lens is broken during handling. With these exceptions, the lens must be considered superior

The overall performance of the Dallos and Lacrilens was comparable. The Lacrilens, while its fitting period was prolonged took less time to fit than the Dallos. Furthermore, the Lacrilens, being plastic, is not so easily broken. The Dallos lens on the other hand, being made of glass, requires no wetting agent, and it is more easily duplicated. While the actual construction of the two lenses is quite different, it is felt that the principle of fitting that allows for aeration of the cornea and a constant flow of lacrimal fluid accounts for their superiority. The Tuohy corneal lens also permits oxygenation of the cornea and tear flow but it has other qualities that seem to make its overall application limited. As long as these principles are observed, it is very likely that in the future a simpler technique of fitting may be devised. The Dallos lens might easily be fitted in plastic as is done by Sarwar at Oxford, England (24). If a finely fitted plastic lens could be coated with silicon, many advantages might be accrued. The relative freedom from breakage of plastic would be retained while scratching would be reduced. The wetting agent would be eliminated and a somewhat greater protection against harmful rays might be possible.

Since such a process is not yet available, it is difficult to claim superiority for either plastic or glass. In view of all the accumulated evidence, the type of contact lens best suited to general military application is a comfortably fitted, vented, corneal-scleral lens, which provides for corneal aeration and for a continual tear flow.

5. Spectacles

In the discussion of spectacles and contact lenses presented herein, emphasis is placed upon the problems of the military rather than those of the civilian. For example, breakage of lenses on the battlefield would present a major problem since the nearest available repair or replacement may be many miles away. The cosmetic factor of contact lenses has not been discussed because it is not a point of major military concern. Consequently in listing the advantages and disadvantages of spectacles, the problems of the field soldier are of prime importance.

The advantages of spectacles are:

Relative ease of fitting and reduplication.
Relative low cost.
Many trained fitters available.

Protection against harmful radiation within the limits of their extent is offered.
Short period of adaptation.
Do not vary the effect of ocular irritants.
Do not cause photophobia.
No development of corneal clouding or edema.
Do not require accessory solutions.
There is no limit upon wearing time.
Partial foreign body protection.

Disadvantages of spectacles are:

Impractical while swimming.
Surfaces may be scratched due to exposed position.
May be dislodged when individual is jarred or jolted.
Easily broken.
Vision may be poor in rain, snow, mud, etc.
Tend to frost over in the cold and steam up upon entering a warm atmosphere.
Perspiration tends to spot the lenses in extremes of heat.
Most headgear is not made to accommodate spectacles, therefore they cause discomfort.
Many sighting devices do not provide for efficient use of spectacles.
Tend to create a mental block while engaged on active duty.
Danger of ocular injury when broken.
Reflect light possibly revealing position.
Gas masks require special inserts.
A number of refractive conditions are not adequately corrected by spectacles.

V. SUMMARY

A comparative study of four types of contact lenses and spectacles was conducted to determine the relative merits of each and the possible application for these lenses in the Armed Forces. Ten selected enlisted men were fitted by professional fitters with each of the four lenses and tests were conducted both in the laboratory and in the field.

In the studies carried out at this laboratory, the fluidless, ventilated lens proved far superior to either the fluid or corneal types. The plastic lens offers greater protection of the eye since it is not as easily broken. The greatest disadvantage to plastic stems from its poor wetting properties.

The cost of contact lenses and the time required for fitting limit their application in the Armed Forces. While they are in many ways superior to spectacles, the limitations do outweigh the advantages for the average serviceman. In view of the many advantages and disadvantages of spectacles, no blanket approval or disapproval of contact lenses may be made. In the many cases of clerical and routine duty where neither spectacles nor contact lenses show to particular advantage, spectacles must be considered superior. It is apparent that contact lenses prove to be superior in many phases of the study as conducted by this laboratory.

VI. RECOMMENDATIONS

A. Study should be encouraged to improve the fitting technique and thereby simplify it and reduce the time required.

B. A technique for hardening or coating plastic with silicon or like substance to eliminate the necessity for wetting agents would be of tremendous value and studies along these lines should be encouraged.

C. The number of individuals skilled in the technique of fitting the newer types of contact lenses is extremely limited, and if the Army accepts them, a limited number of long term personnel should be schooled to do the fittings. Should the demand increase, these trained individuals could serve as a nucleus for the training of additional fitters.

D. Contact lenses can be recommended for:

1. Personnel who are extremely valuable to the Armed Forces because of their skill, training, and experience and whose visual acuity, with the usual visual aids, is not adequate to meet the requirements but may be with contact lenses. Such eye conditions as high myopia, high astigmatism, irregular astigmatism, corneal leukomata, keratoconus, aphakia, etc., are frequently adequately corrected with contact lenses.

2. Another group who might be retained or made available on the basis of adequate correction by contact lenses but are otherwise lost to the services are those with injuries to the face and lids that result in lagophthalmus, ectropian, corneal exposure, etc.

3. Personnel requiring visual correction whose field efficiency might be enhanced greatly if contact lenses were substituted for spectacles. Due to the aforementioned limitations of contact lenses, they should be restricted to outstanding individuals or situations such as Arctic duty, divers, "Frogmen", etc.

VII. BIBLIOGRAPHY

1. Smelser, G. K. The study of basic physiology of the cornea as it is affected by the wearing of contact lenses. Contract No. W-49-007-MD-451. Final Report. 1951.

2. Finkelstein, Isadore S. The biophysics of corneal scatter and diffraction of light induced by contact lenses. Thesis, Columbia University.

3. Obrig, T. E. Contact Lenses 1947. The Chilton Company, Philadelphia, Pa.

4. Plymale, W. S. Sr., and D. F. Hansen. Stabilized Circuit for Photomultipliers. Electronics Vol. 23 No. 2, Pp. 102-3. February 1950.

5. Subcommittee on Procedures and Standards for Visual Examination of the Army-Navy NRC Vision Committee. Studies Visual Acuity. Department of the Army, The Adjutant General's Office 1948.

6. Lythgoe R. J. The measurement of visual acuity. Medical Research Council Special Report Ser. 173, 1932. H. M. Stationery Office.

7. Donaldson, D. D. Personal communication.

8. Crouch, C. L. The relationship between illumination and vision. Illumination Engineering Vol. 40, P747. November 1945.

9. Holladay, L. L. The fundamentals of glare and visability. Journal of the Optical Society of America Vol. 12, P. 271, April 1926.

10. Harrison, W. Glare ratings. Illuminating Engineering Vol 40, P 525. September 1945.

11. Cobb, P. W. The effect on foveal vision of bright surroundings IV. J. Exp. Psychology. Vol. 1, P. 540, 1916.

12. Peterson, J. H. and E. Simonson. The effect of glare on accommodation near point. Amer. J. Ophth. Vol. 34, P. 1088. 1951

13. Blum, H. Radiation, photophysiologic, and photo-pathologic processes. Medical Physics. Vol. 1, P. 1145. The Year Book Publishers, Inc. Chicago, Ill. 1944.

14. Lebensohn, J. E. The nature of photophobia. Arch. of Ophth. Vol. 12, P. 380. 1934.

15. Friedenberg, P. On the origin of the pain in photophobia and the blepharospastic syndrome. Ophth. Rec. Vol. 14, P. 357, 1905.

16. Alpern, M. Accommodation and convergence with contact lenses. Amer. J. Optom. and Arch. Am. Acad. Optom. Vol. 26, P. 379, 1949.

17. Alpern, M. Further comment on accommodation and convergence with contact lenses. Amer. J. Optom. and Arch. Am. Acad. Optom. Vol. 27, P. 238, 1950.

18. Firestone, L. E. and E. M. Gaynes. Contact lenses and their effect on neuro-muscular patterns of vision. Amer. J. Optom. and Arch. Am. Acad. Optom. Vol. 26, P. 95, 1949.

19. McFarland, R. A., J. N. Evans, M. H. Halperin. Ophthalmic aspects of acute oxygen deficiency. Arch. of Ophth. Vol. 26, P. 886, 1941.

20. Weaver, E. M. F. The importance of vision in aviators. J. Aviation Medicine. Vol. 14, P. 289, 1943.

21. Alluisi, E. A. et al. Binocular stereoptic acuity and spatial localization as criteria for the evaluation of contact lenses. Army Medical Research Laboratory, Fort Knox, Ky. Report No. 70, Dec 1951.

22. Alluisi, E. A., K. Inaba, and F. L. Nungesser, Jr. Changes in visual depth perception with the wearing of contact lenses. Report No 105. 2 December 1952

23. Lindsey, D. and T. G. Nelson. Basic Airborne Training, U. S. Armed Forces Med. J. Vol. 2, P. 1027, 1951.

24. Sarwar, M. Personal Communication.

TABLE I

AGES AND REFRACTIVE DATA OF SUBJECTS

SUBJECT	AGE *	VISUAL ACUITY						CYCLOPLEGIC ACCEPTANCE	
		UNCORRECTED			CORRECTED				
		O D	O S	O U	O D	O S	O U	O D	O S
R G A	22	20/200-	20/200	20/200+	20/15	20/15	20/15	- 2.75 • -0.75 X 120	- 2.75 • -0.75 X 68
J L A	21	20/200	20/300	20/200	20/15	20/15	20/15	- 2.50 • -0.25 X 90	- 2.50 • -0.50 X 90
C J D	22	20/60-	20/60-	20/60+	20/15	20/15	20/15	- 0.75 • -0.75 X 110	- 0.50 • -0.75 X 25
J L E	22	20/100	20/20	20/20	20/15	20/15	20/15	+ 4.25 • -2.50 X 3	+ 3.00 • -1.00 X 5
D J F	20	20/300	20/200	20/200	20/15	20/15	20/15	- 3.25	- 2.75 • -0.50 X 180
J K H	26	20/15	20/80	20/15	20/15	20/60	20/15	+ 3.75 • -0.25 X 90	+ 3.75 • -0.50 X 90
D R M	22	20/200	20/200	20/200	20/15	20/15	20/15	- 3.75 • -1.25 X 175	- 2.75 • -1.00 X 5
L F P	22	20/400	10/400	20/400	20/20	20/20	20/15	- 4.00 • -4.00 X 3	- 4.00 • -4.00 X 180
E J S	22	20/400	10/400	20/400	20/20+	20/20	20/20+	- 3.50	- 5.25 • -0.25 X 180
J L W	20	20/200	20/200	20/200	20/20	20/20	20/20	+10.00 • -2.50 X 175	+10.00 • -1.75 X 175

* AS OF 15 APRIL 1951

200 200 200 20 20 20 +10.00 • -2.50 X 175 +10.00 • -1.75 X 175

* AS OF 15 APRIL 1951

TABLE 2

LENSES WORN BY SUBJECTS PER CYCLE

SUBJECT	CYCLES-1952				
	1 7 JAN — 7 MAR	2 10 MAR — 6 MAY	3 7 MAY — 26 JUNE	4 27 JUNE — 22 JULY	5 23 JULY — 19 AUG
R G A	TUOHY	SPECTACLES	FLUID	DALLOS	LACRILENS
J L A	TUOHY	SPECTACLES	FLUID	DALLOS	LACRILENS
C J D	FLUID	DALLOS	LACRILENS	TUOHY	SPECTACLES
J L E	SPECTACLES	FLUID	DALLOS	LACRILENS	TUOHY
D J F	LACRILENS	TUOHY	SPECTACLES	FLUID	DALLOS
J K H	DALLOS	LACRILENS	TUOHY	SPECTACLES	FLUID
D R M	FLUID	DALLOS	LACRILENS	TUOHY	SPECTACLES
L F P	DALLOS	LACRILENS	TUOHY	SPECTACLES	FLUID
E J S	LACRILENS	TUOHY	SPECTACLES	FLUID	DALLOS
J L W	SPECTACLES	FLUID	LACRILENS	DALLOS	TUOHY

| J LW | SPECTACLES | FLUID | LACRILENS | DALLOS | TUOHY |

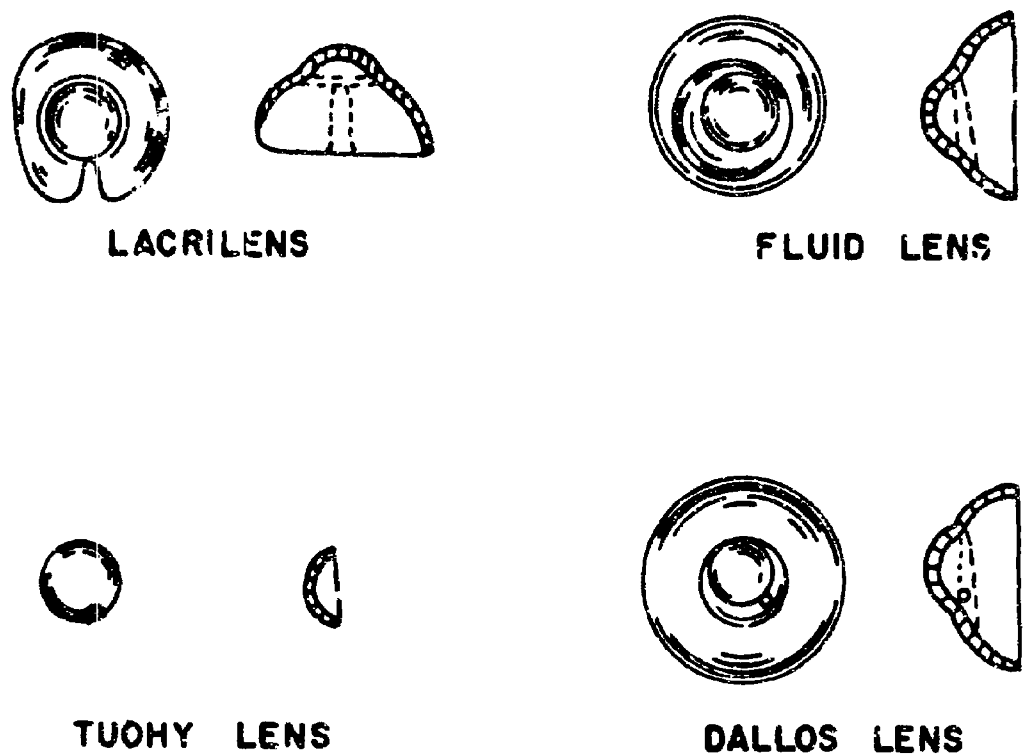


FIG. I – SCHEMATIC PRESENTATION OF LENSES STUDIED–LEFT LENS SHOWN

STUDIED–LEFT LENS SHOWN

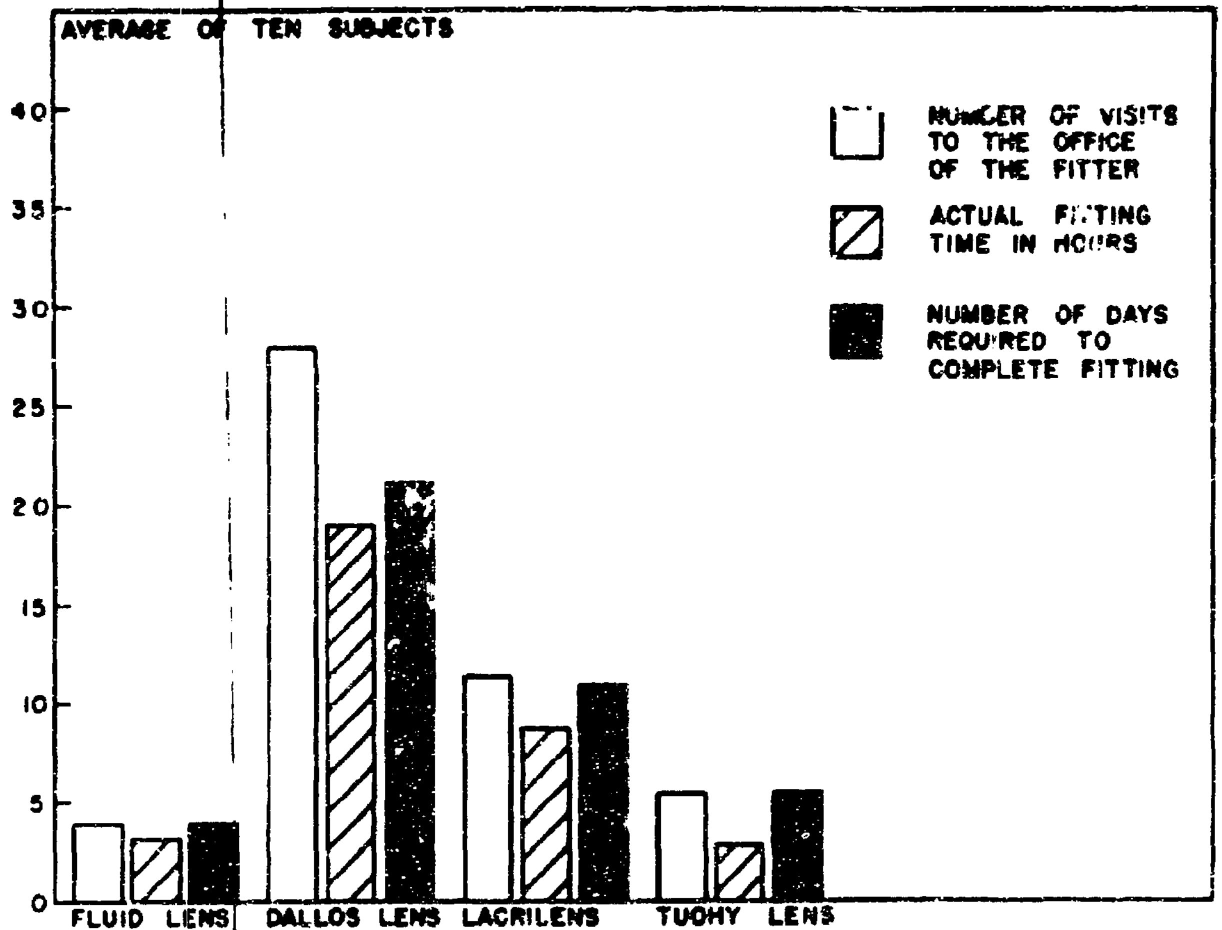


FIG. 2 COMPARATIVE CONTACT LENS FITTING DATA

FLUID LENS DALLOS LENS LACRILENS TUOHY LENS

FIG. 2 COMPARATIVE CONTACT LENS FITTING DATA

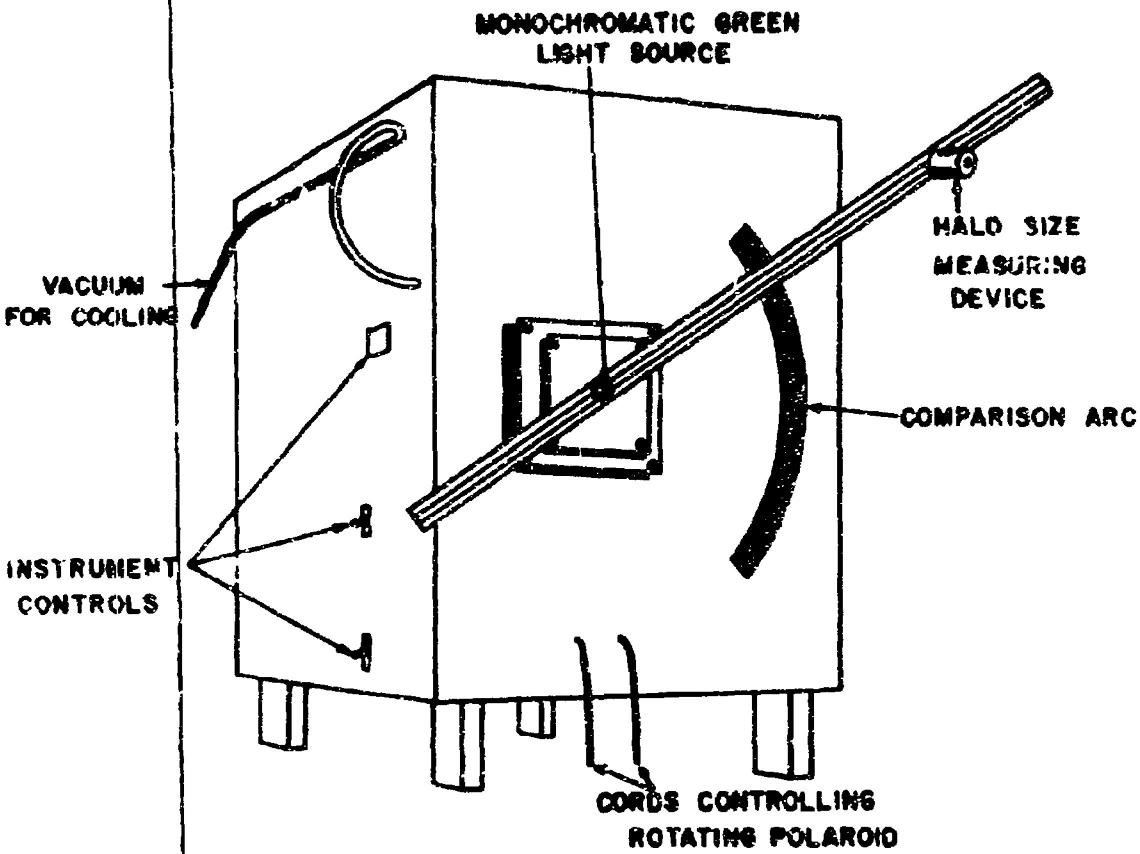


FIG. 3 HALOMETER

FIG. 3 HALOMETER

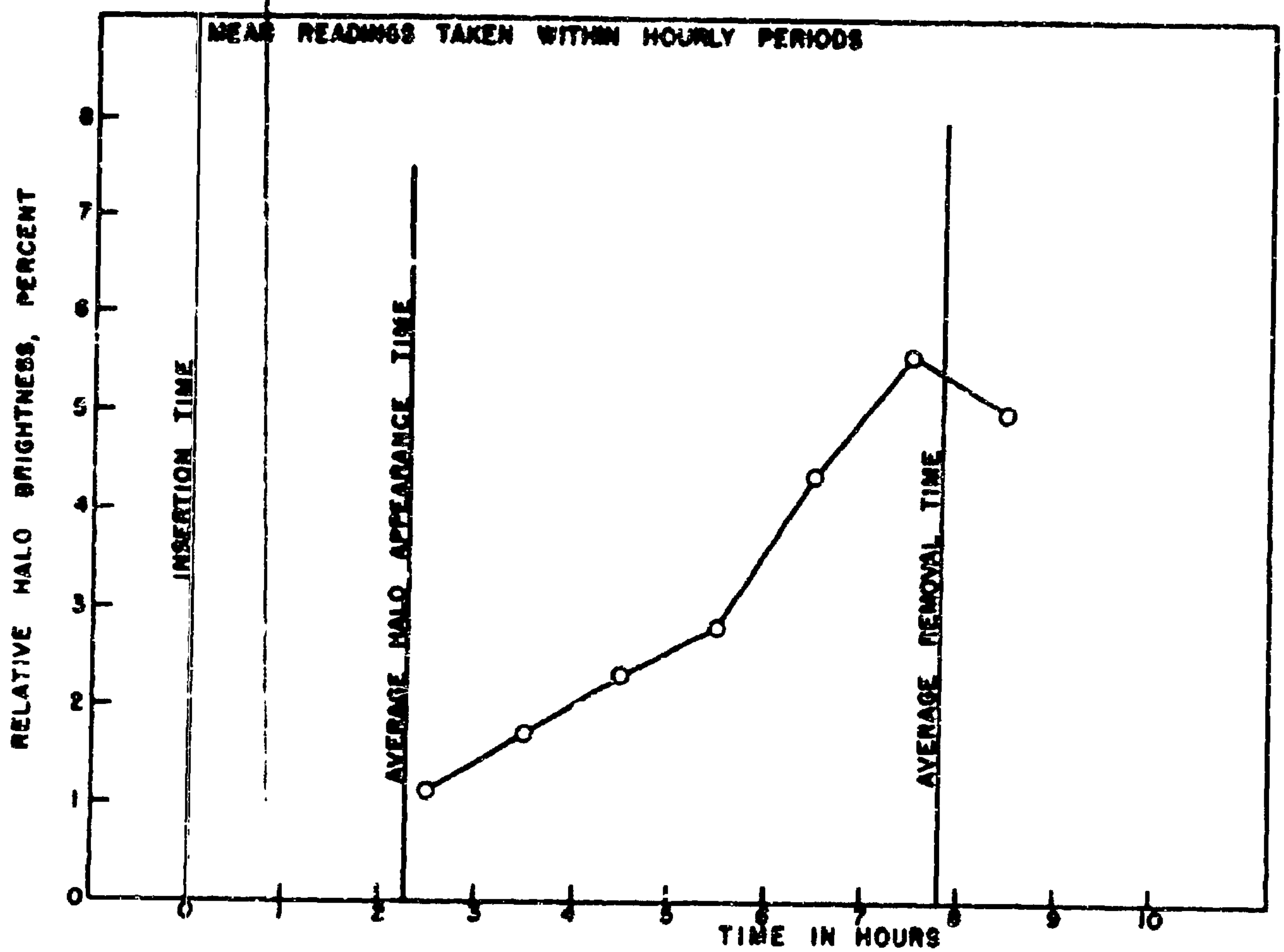


FIG. 4 FLUID LENS HALOMETRY

TIME IN HOURS

FIG. 4 FLUID LENS HALOMETRY

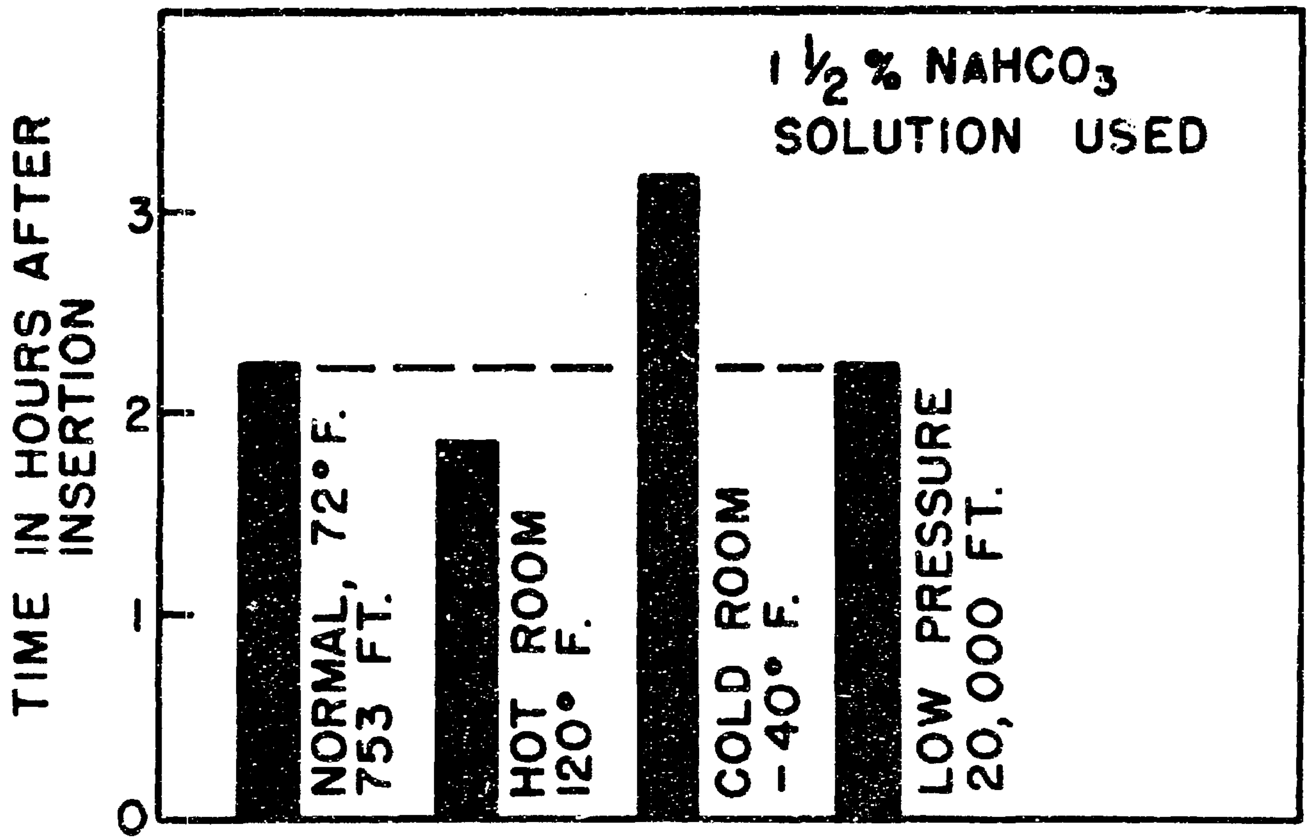
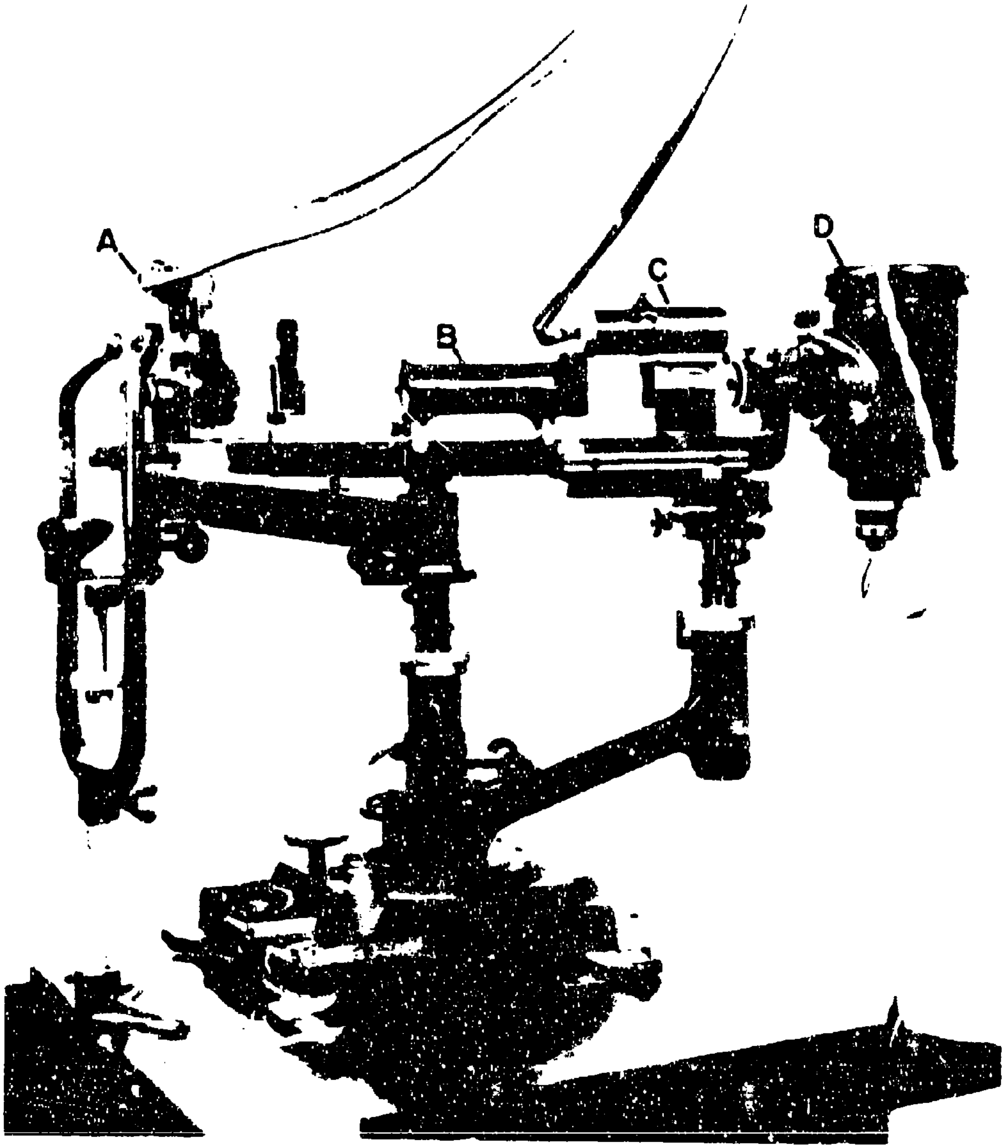


FIG. 5 FLUID LENS, AVERAGE HALO APPEARANCE TIME

APPEARANCE TIME



A - DETECTOR
B - FILTER HOLDER AND CROSS HAIRS
C - MONITOR
D - LAMP HOUSING

FIG. 6 - SLIT LAMP PHOTOMETER

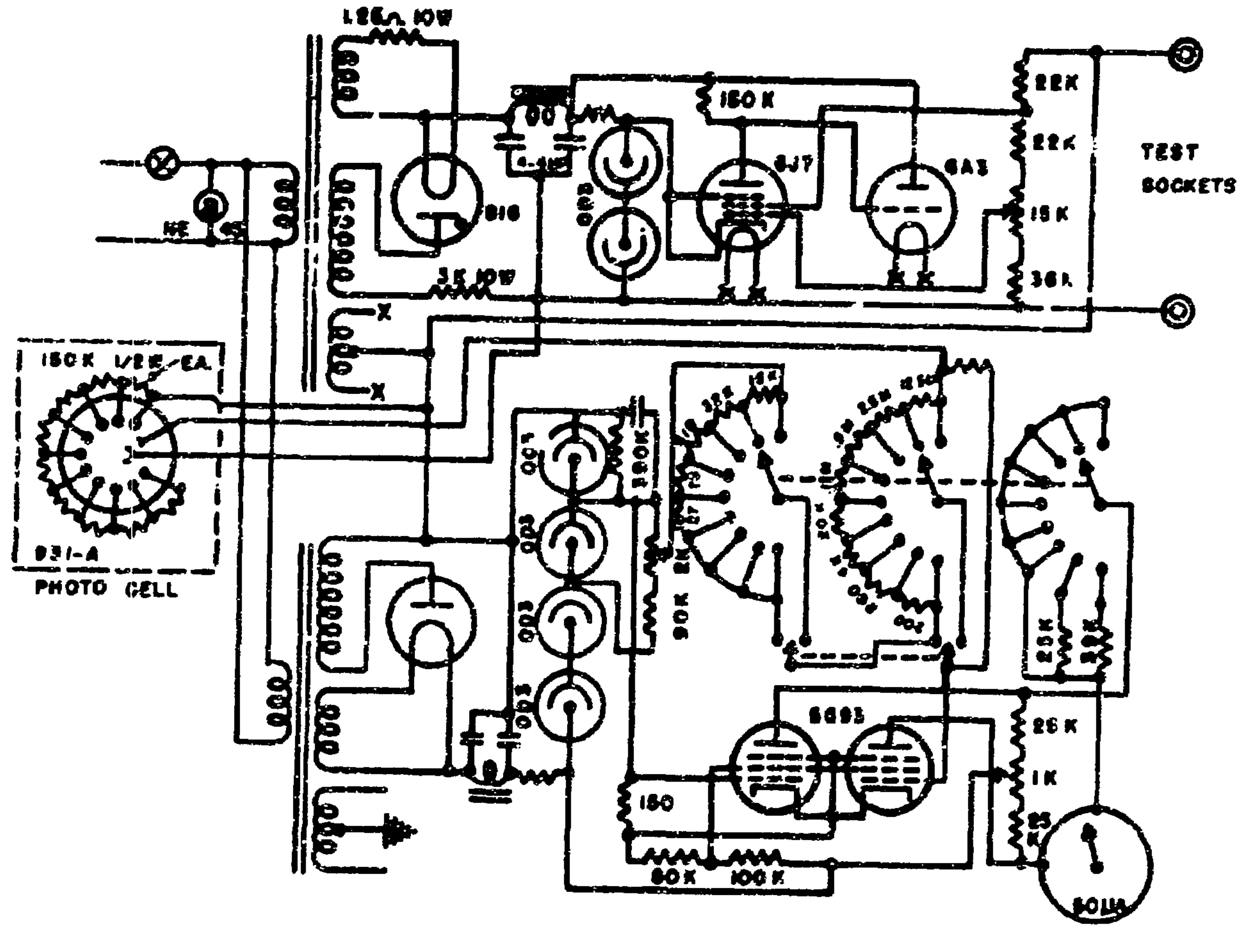


FIG. 7 PHOTO CELL MONITOR FOR SLIT LAMP CONTROL

FIG. 7 PHOTO CELL MONITOR FOR SLIT LAMP CONTROL

METER

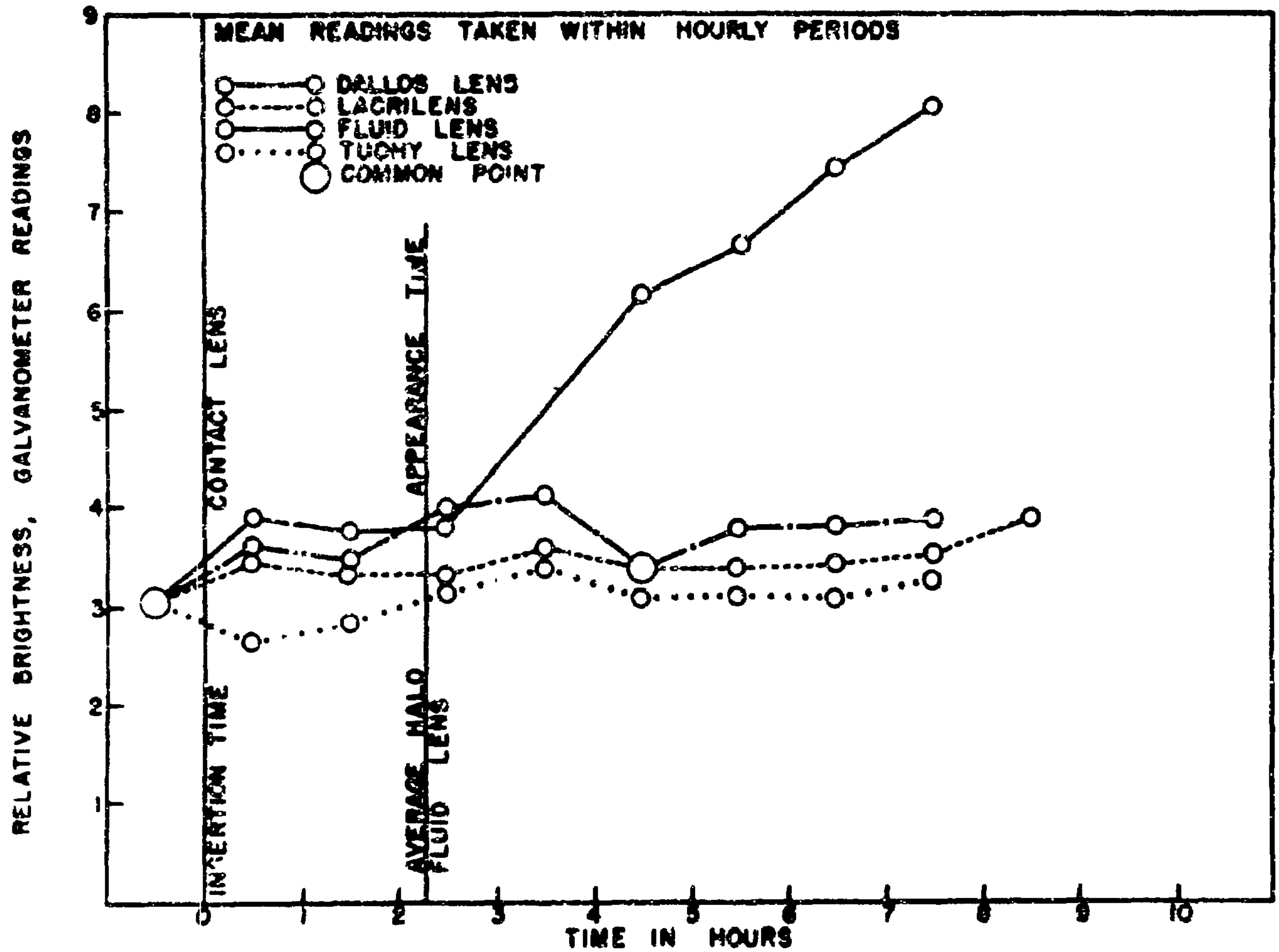


FIG. 8 PHOTOMETRIC READINGS OF CORNEAL SCATTER WITH CONTACT LENS

TIME IN HOURS

FIG. 8 PHOTOMETRIC READINGS OF CORNEAL SCATTER WITH CONTACT LENS

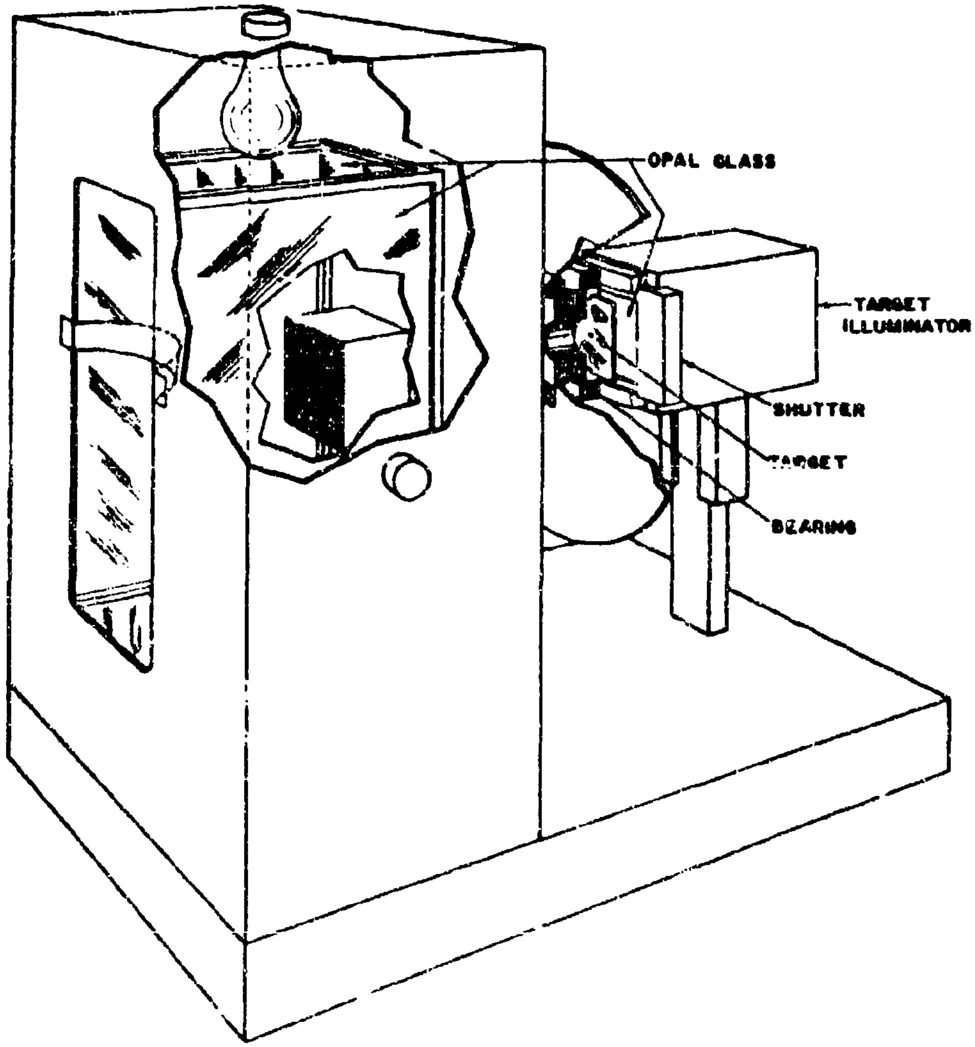


FIG. 9 PERSPECTIVE VIEW OF VISUAL ACUITY TEST APPARATUS

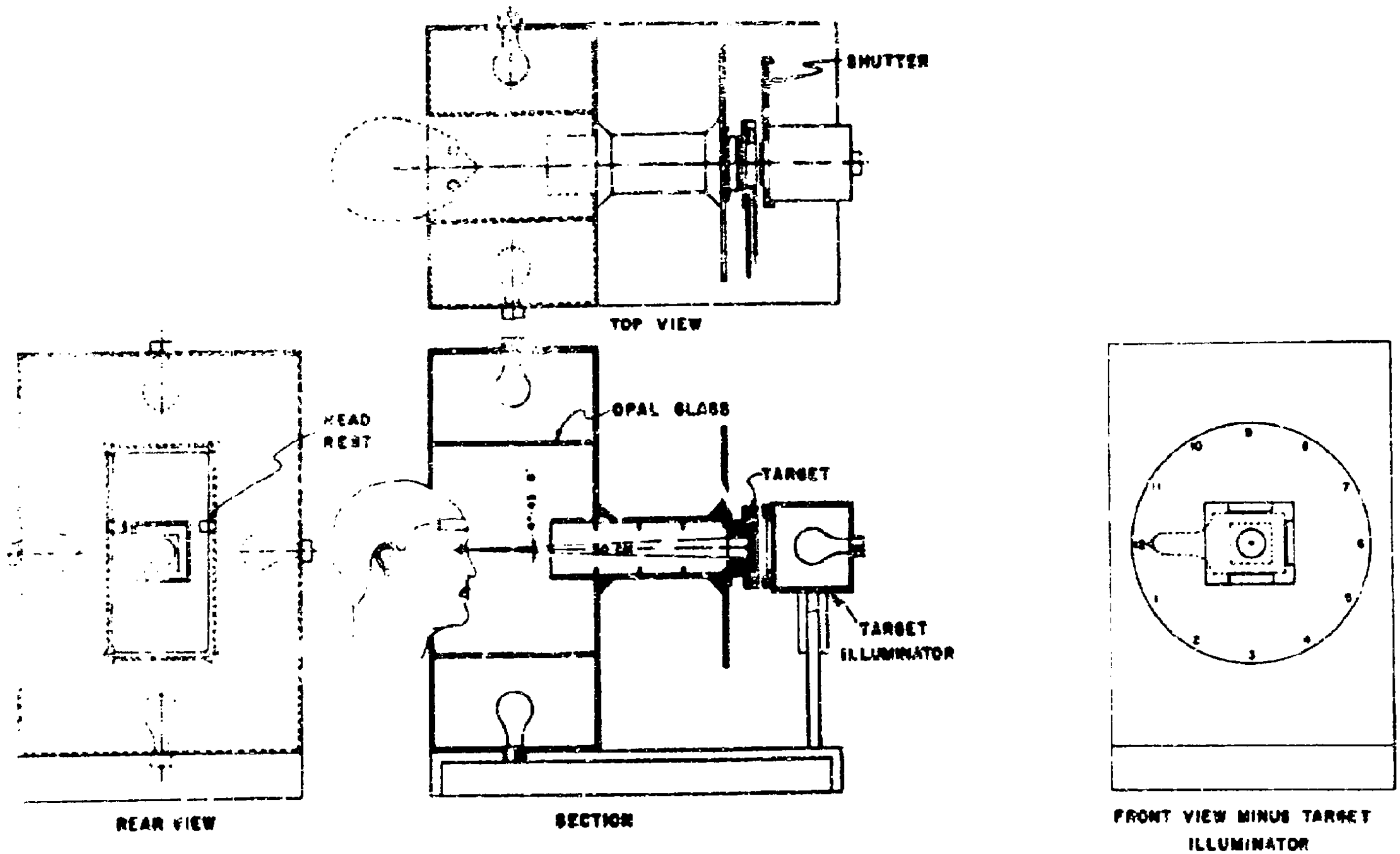
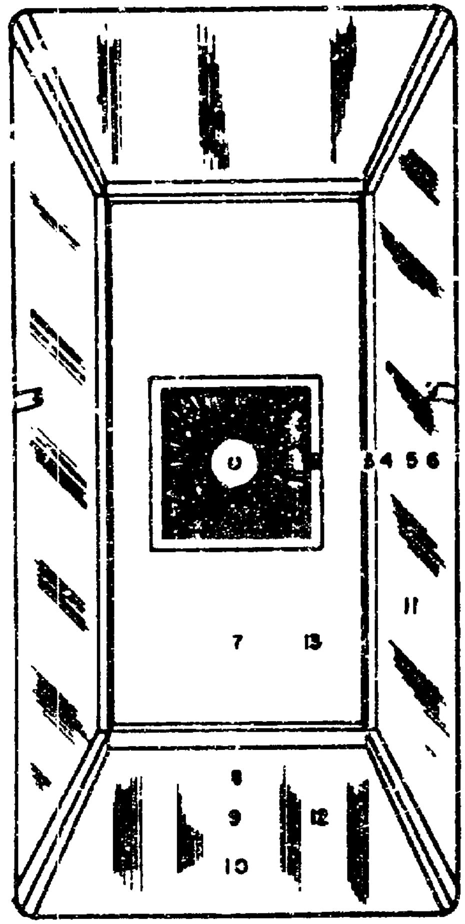


FIG. 10 VISUAL ACUITY TEST APPARATUS



SURROUND ILLUMINATION = 100 Ft. C.
AS MEASURED WITH A WESTON FOOT-CANDLE METER MODEL-614. PLACED IN THE POSITION OF THE MONOCULAR EYE.

POINT	ANGLE IN DEGREES FROM CENTER OF ROTATION OF THE MONOCULAR EYE — HORIZ.	VERT.	SAGITAL FROM HORIZ.	FOOT LAMBERTS
C	.0°	0°	0°	0.632
1	5.5°	0°	0°	2.35
2	16.0°	0°	0°	87.8
3	22.5°	0°	0°	67.3
4	32.5°	0°	0°	187.5
5	41.5°	0°	0°	203.0
6	58.0°	0°	0°	173.3
7	0°	26°	0°	90.33
8	0°	45°	0°	191.33
9	0°	59°	0°	196.5
10	0°	75°	0°	164.0
11	43.0°	40°	55°	169.6
12	25.0°	60°	89°	172.7
13	11.0°	26°	71°	91.6

FIG. 11 MEASURMENT OF SURROUND LIGHTING

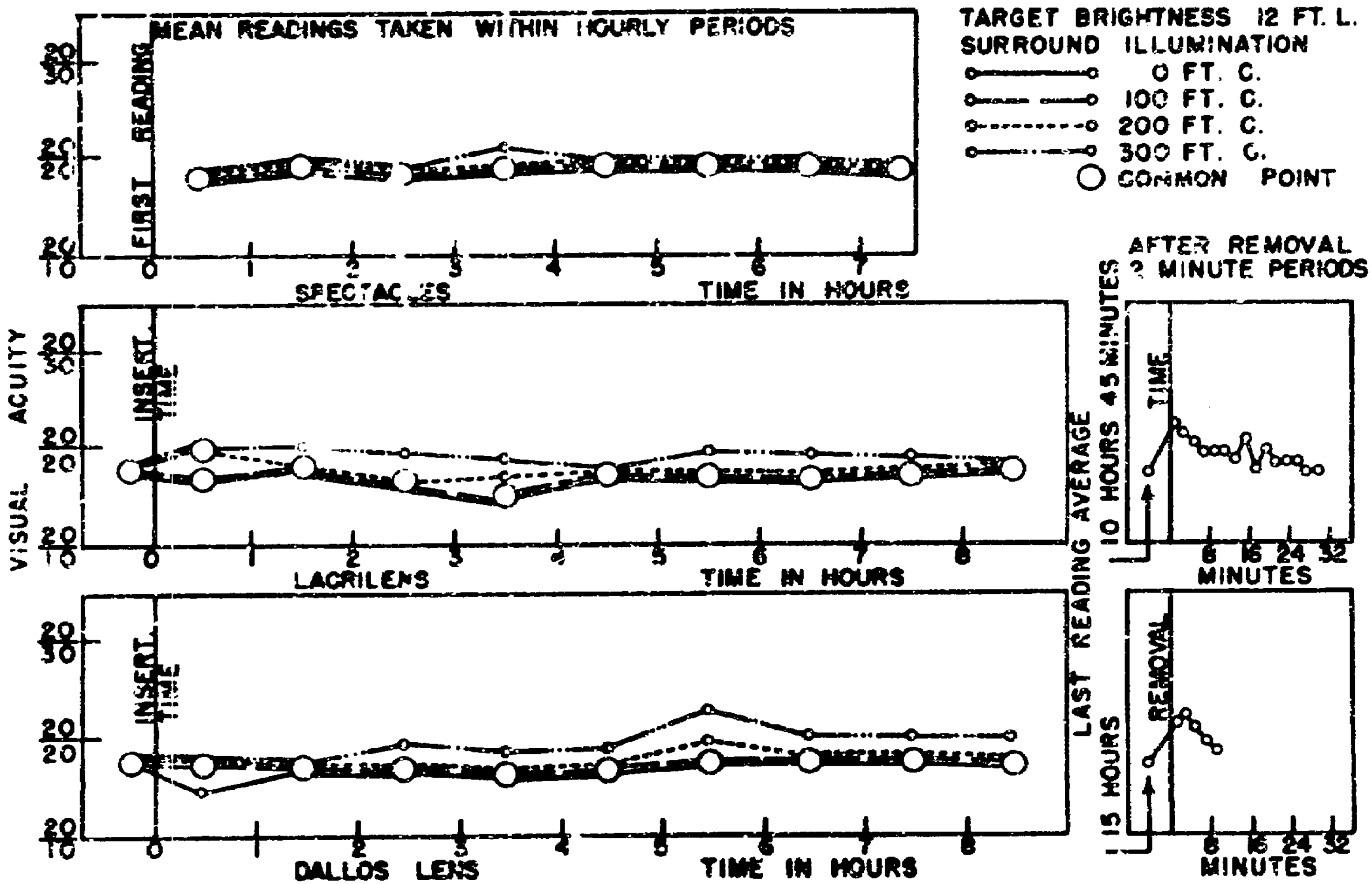


FIG. 12 VISUAL ACUITY TESTED AT 20 FEET

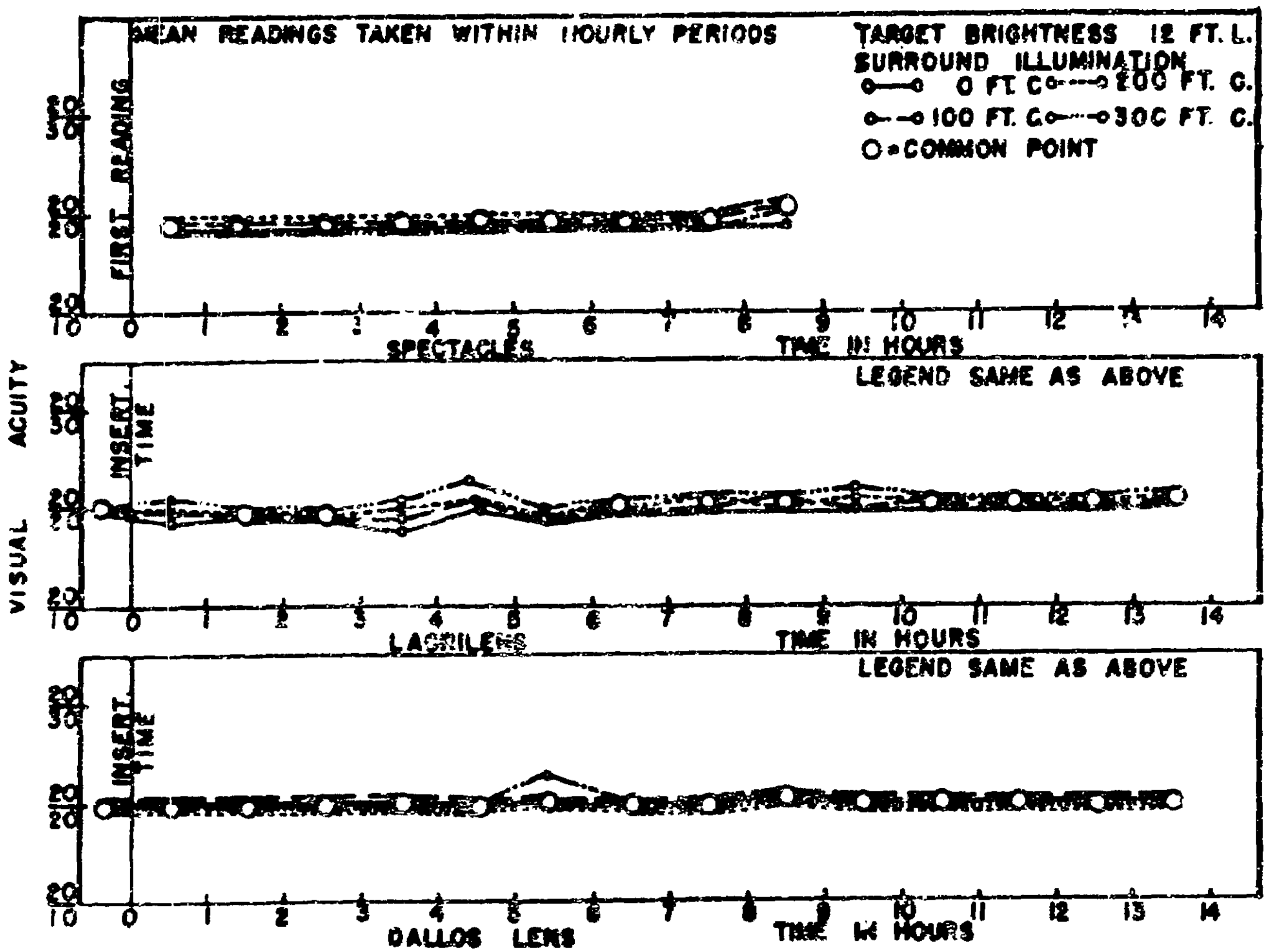


FIG. 13 VISUAL ACUITY TESTED AT 50 CENTIMETERS

FIG. 13 VISUAL ACUITY TESTED AT 50 CENTIMETERS

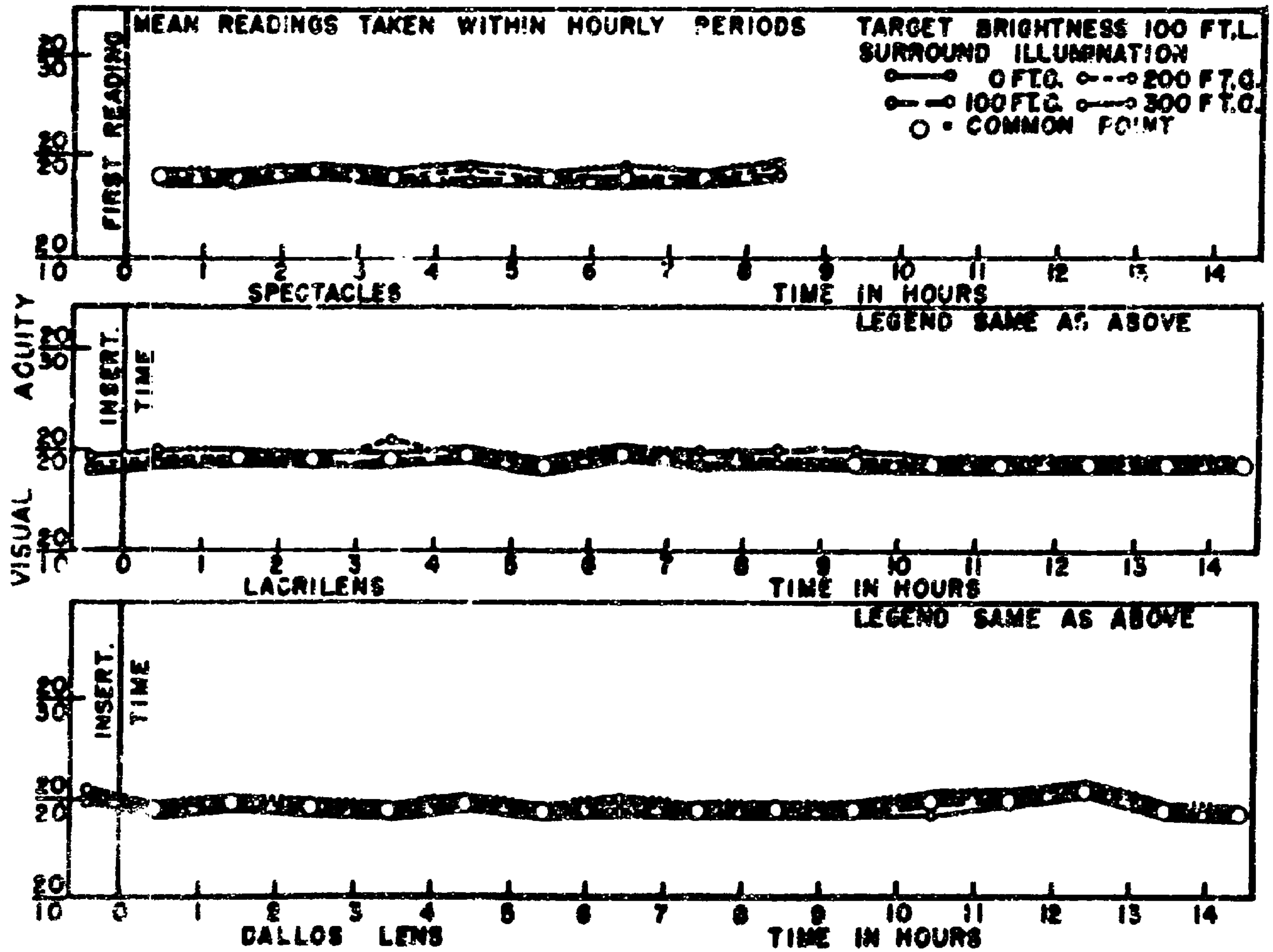


FIG. 14 VISUAL ACUITY TESTED AT 80 CENTIMETERS

DALLOS LENS TIME IN HOURS
FIG. 14 VISUAL ACUITY TESTED AT 80 CENTIMETERS

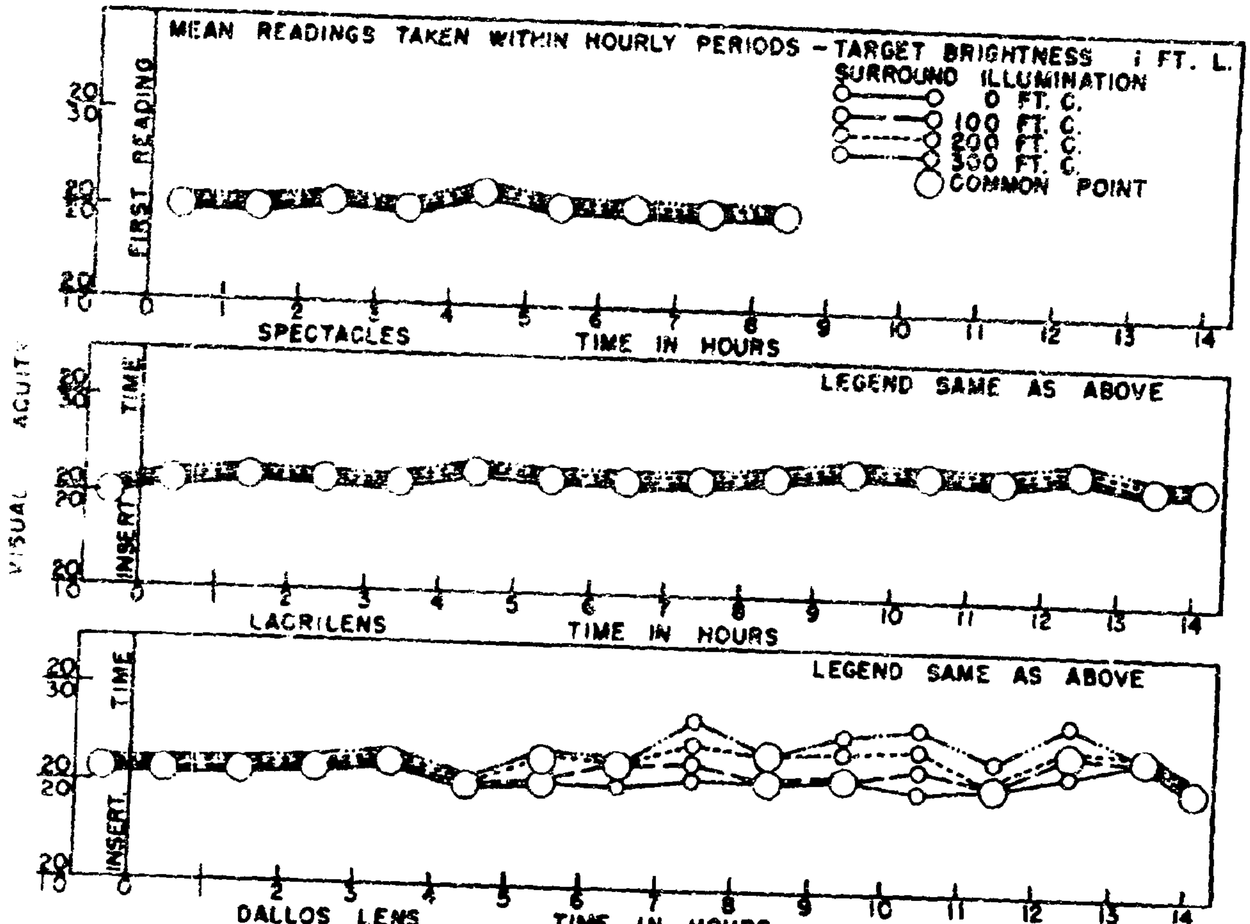


FIG 15 VISUAL ACUITY TESTED AT 50 CENTIMETERS

DALLOS LENS TIME IN HOURS
FIG. 15 VISUAL ACUITY TESTED AT 50 CENTIMETERS

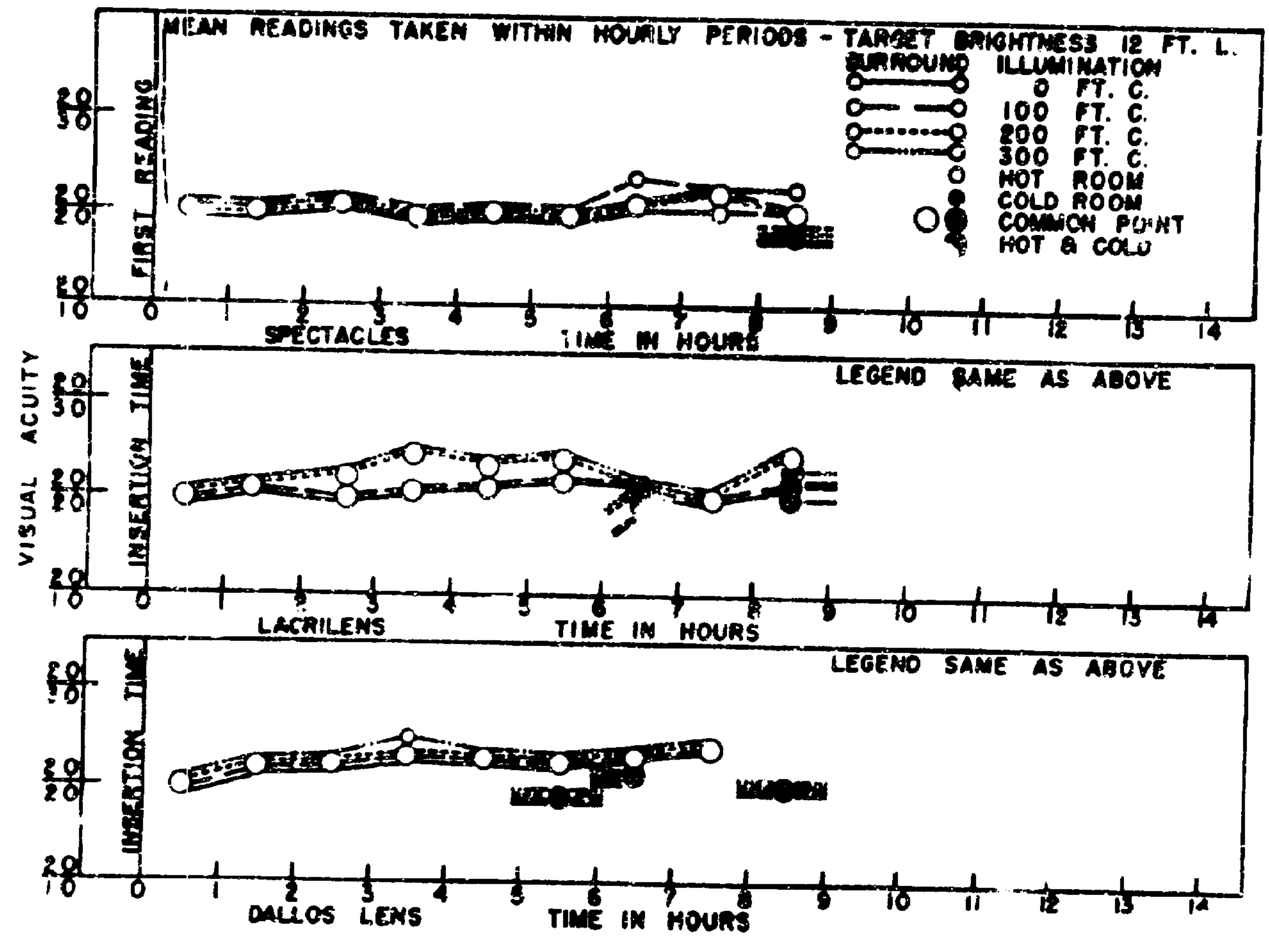


FIG. 16 VISUAL ACUITY TESTED AT 50 CENTIMETERS, HOT AND COLD ROOMS

TIME IN HOURS

FIG. 16 VISUAL ACUITY TESTED AT 50 CENTIMETERS, HOT AND COLD ROOMS

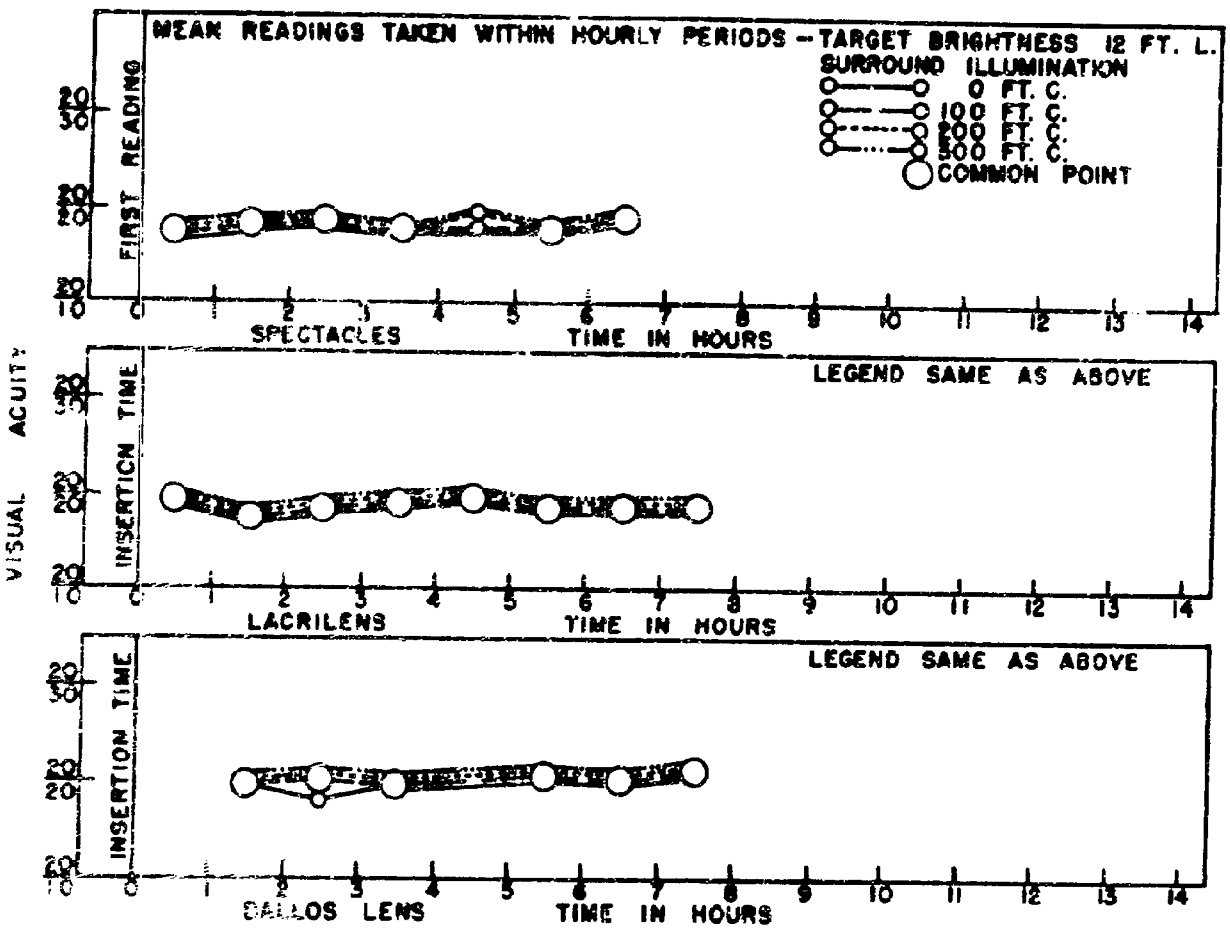


FIG. 17 VISUAL ACUITY TESTED AT 50 CENTIMETERS IN LOW PRESSURE CHAMBER AT 20,000 FEET

CHAMBER AT 20,000 FEET

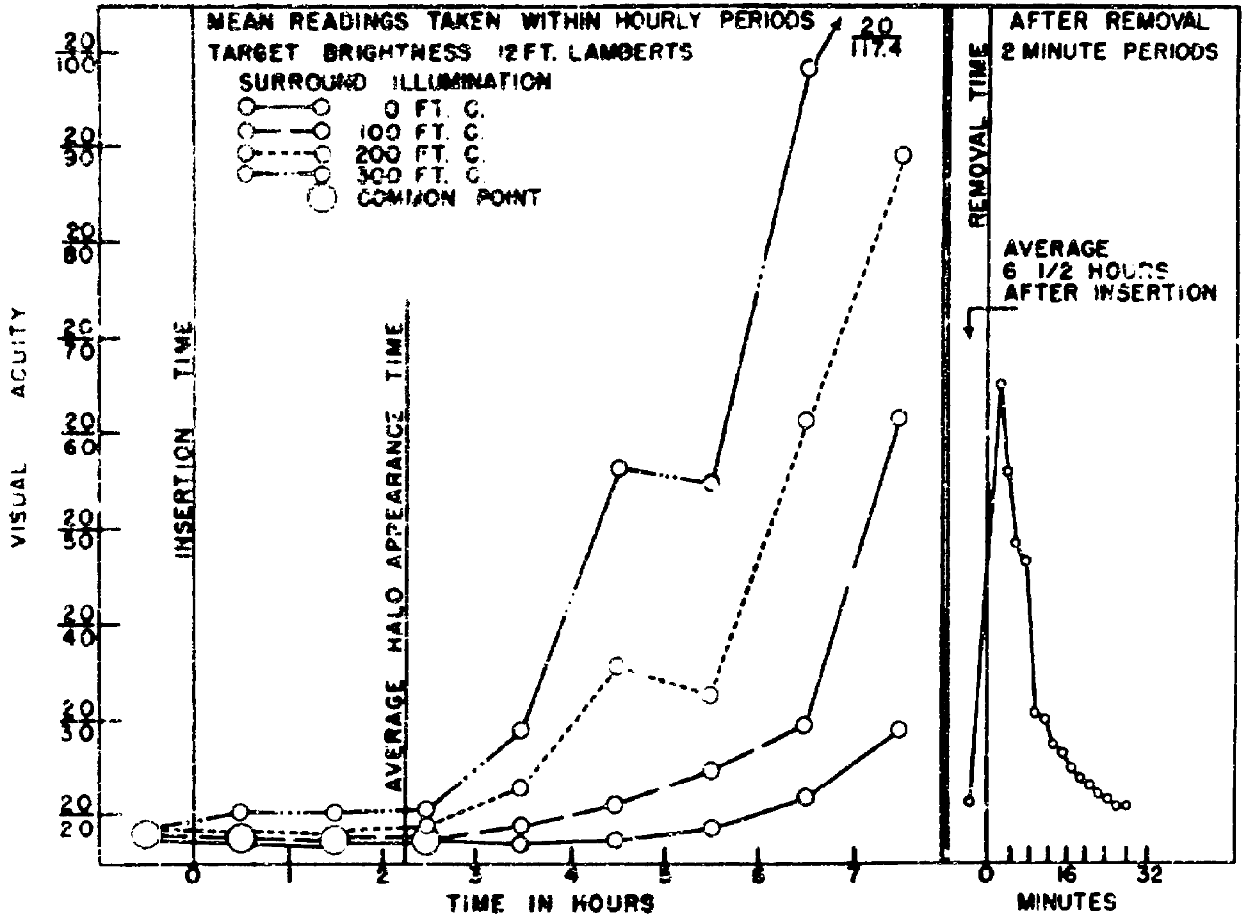


FIG. 18 FLUID LENS, VISUAL ACUITY TESTED AT 20 FEET

FIG. 18 FLUID LENS, VISUAL ACUITY TESTED AT 20 FEET

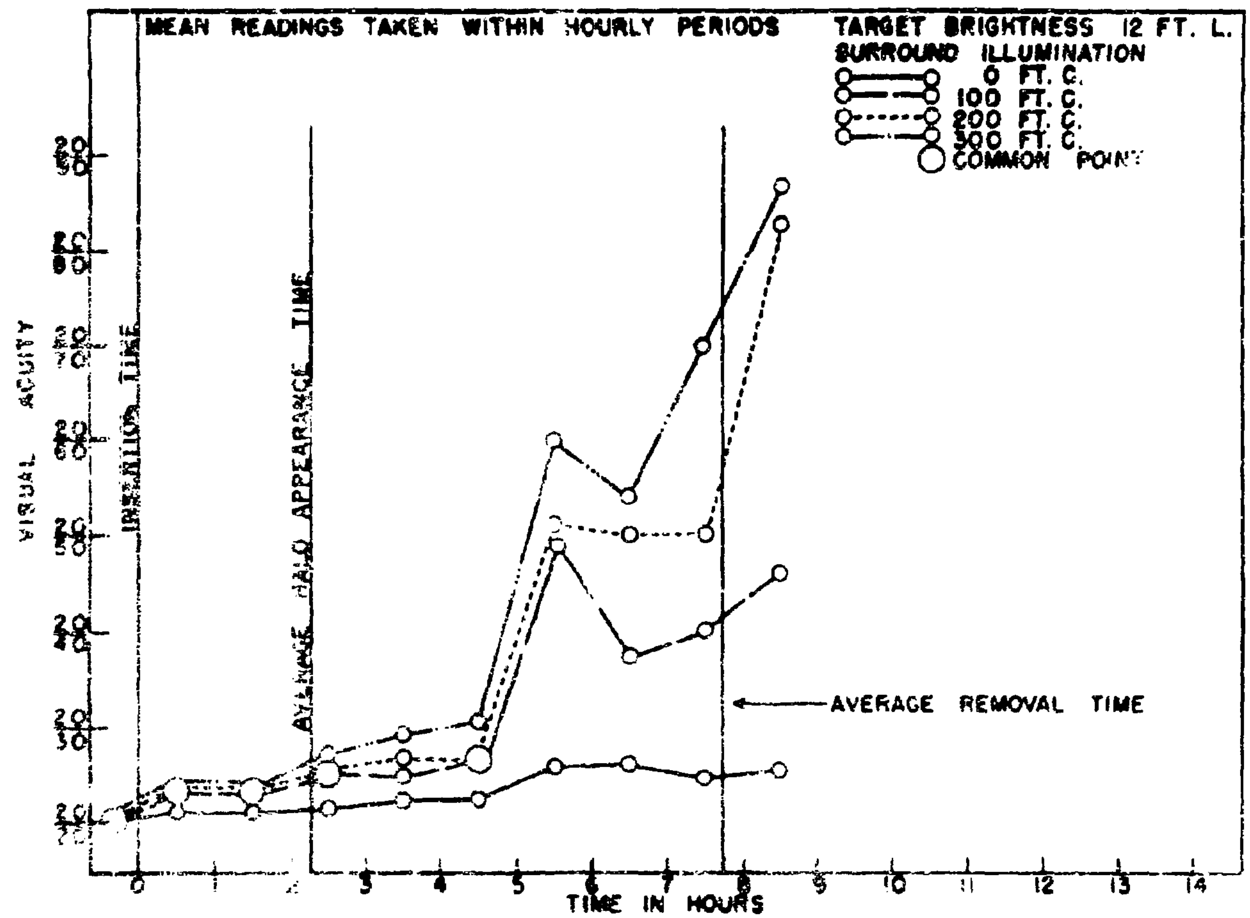


FIG. 19 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

FIG. 19 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

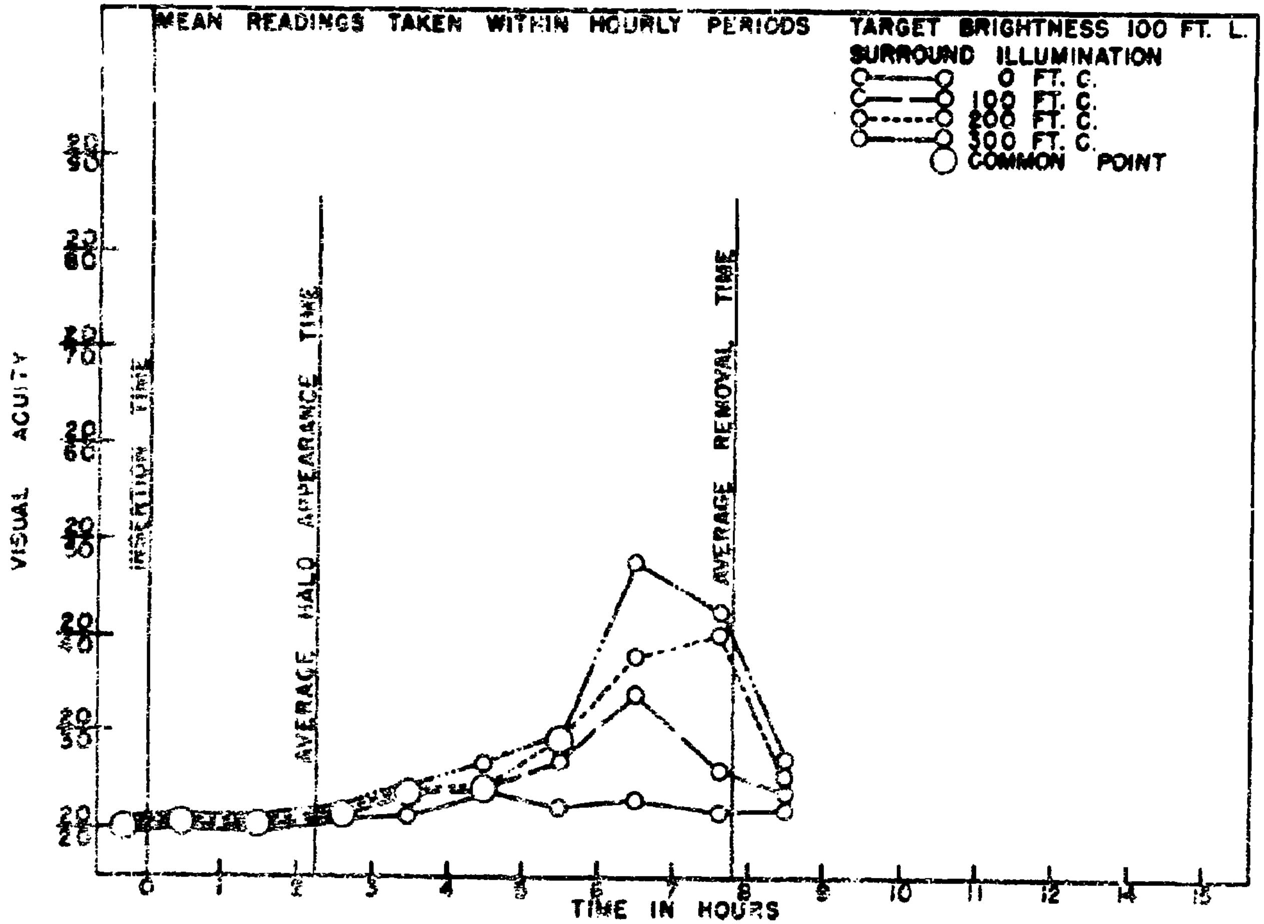


FIG. 20 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

TIME IN HOURS

FIG. 20 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

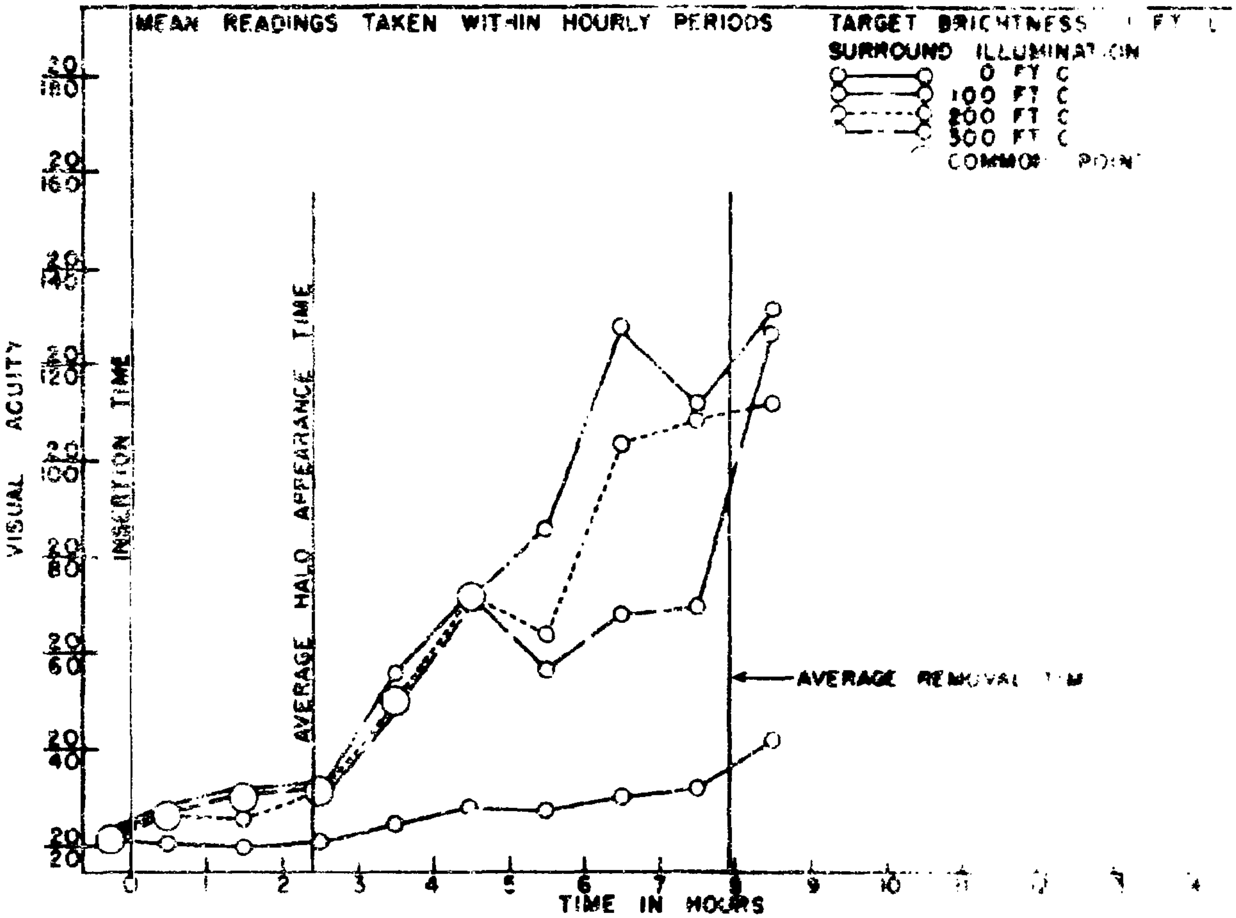


FIG 21 FLUID LENS, VISUAL ACUITY TESTED AT 30 CENTIMETERS
NOTE REDUCED SCALE

TIME IN HOURS
FIG. 21 FLUID LENS, VISUAL ACUITY TESTED AT 30 CENTIMETERS
NOTE REDUCED SCALE

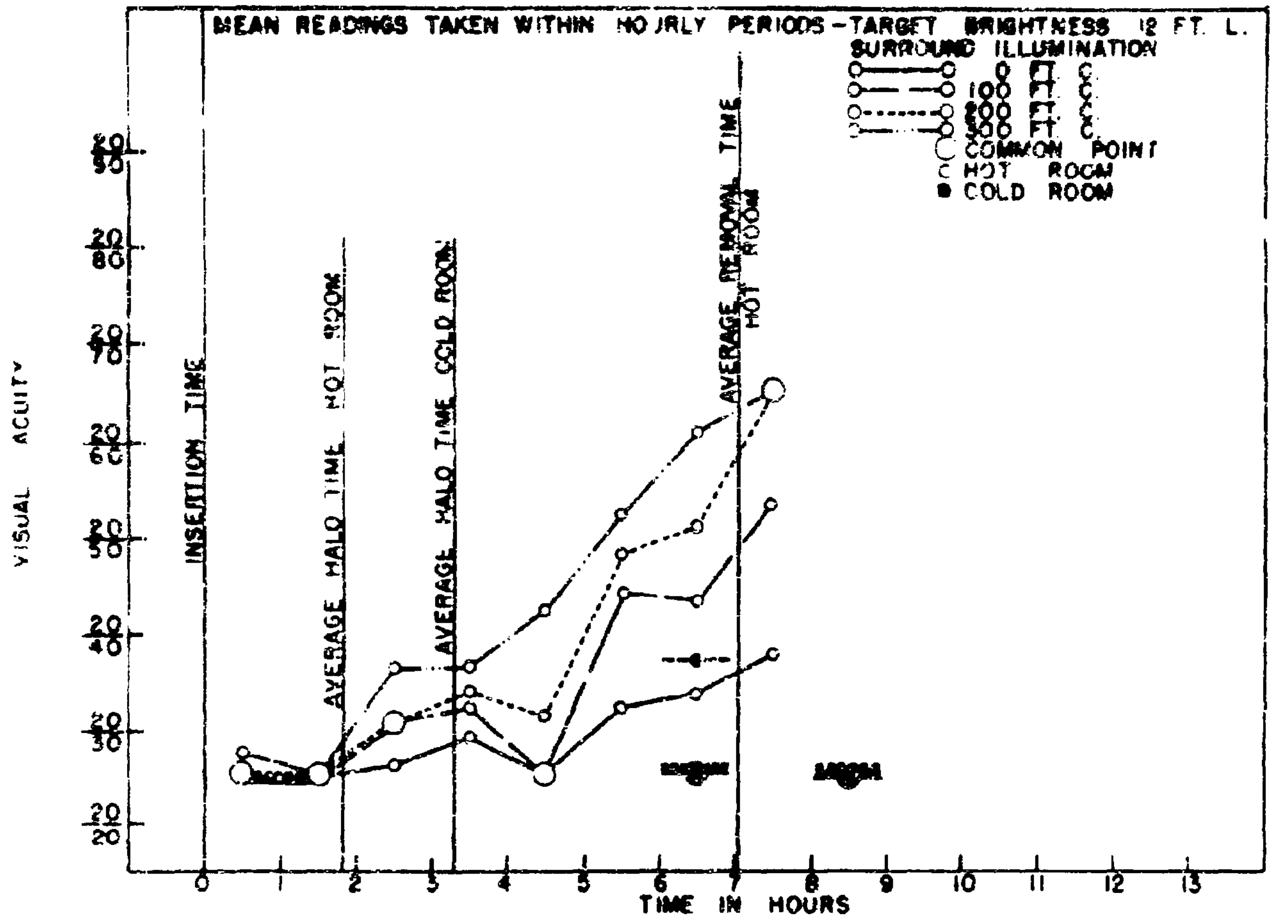


FIG 22 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS IN HOT ROOM AND COLD ROOM

TIME IN HOURS

FIG 22 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS IN HOT ROOM AND COLD ROOM

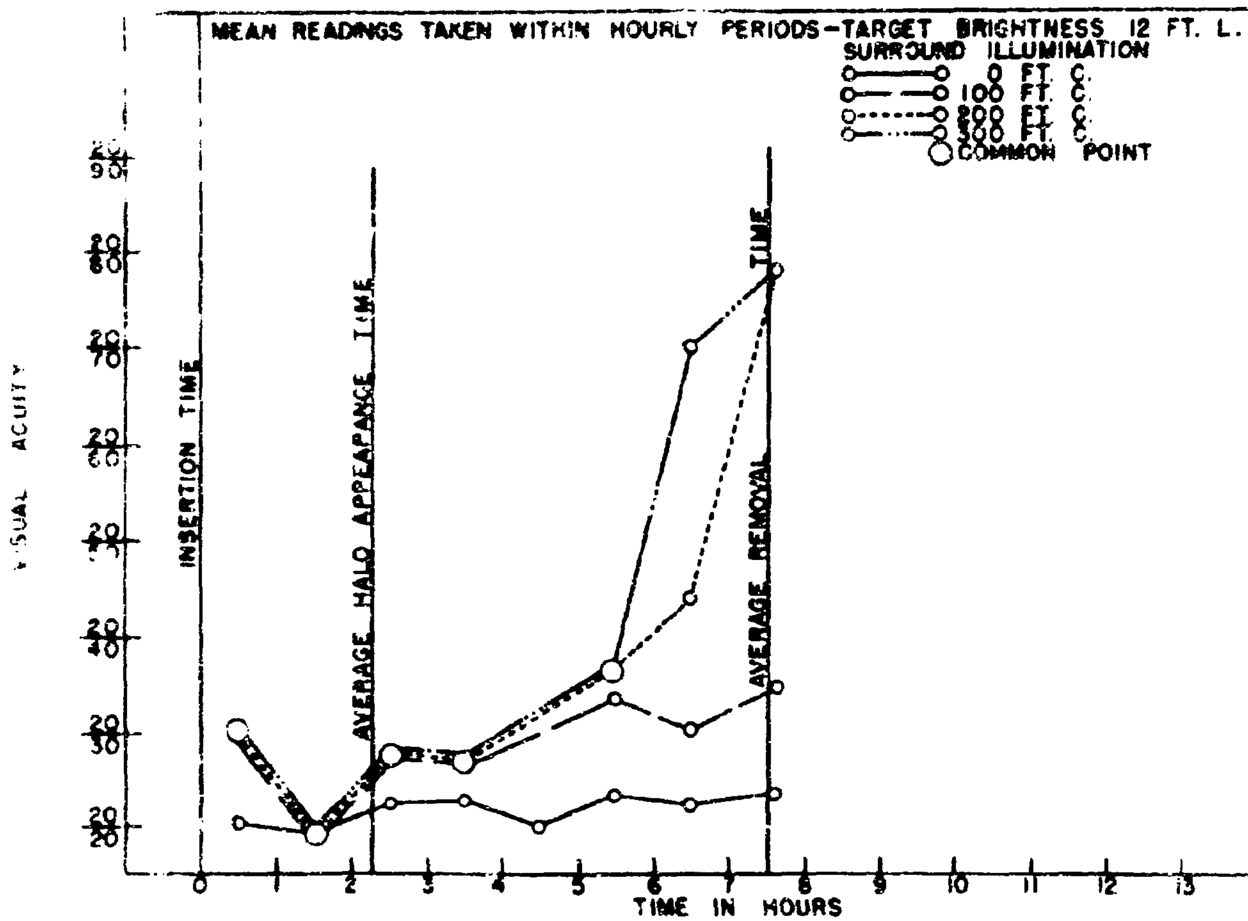


FIG 23 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS IN LOW PRESSURE CHAMBER AT 20,000 FEET

FIG. 23 FLUID LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS IN LOW PRESSURE CHAMBER AT 20,000 FEET

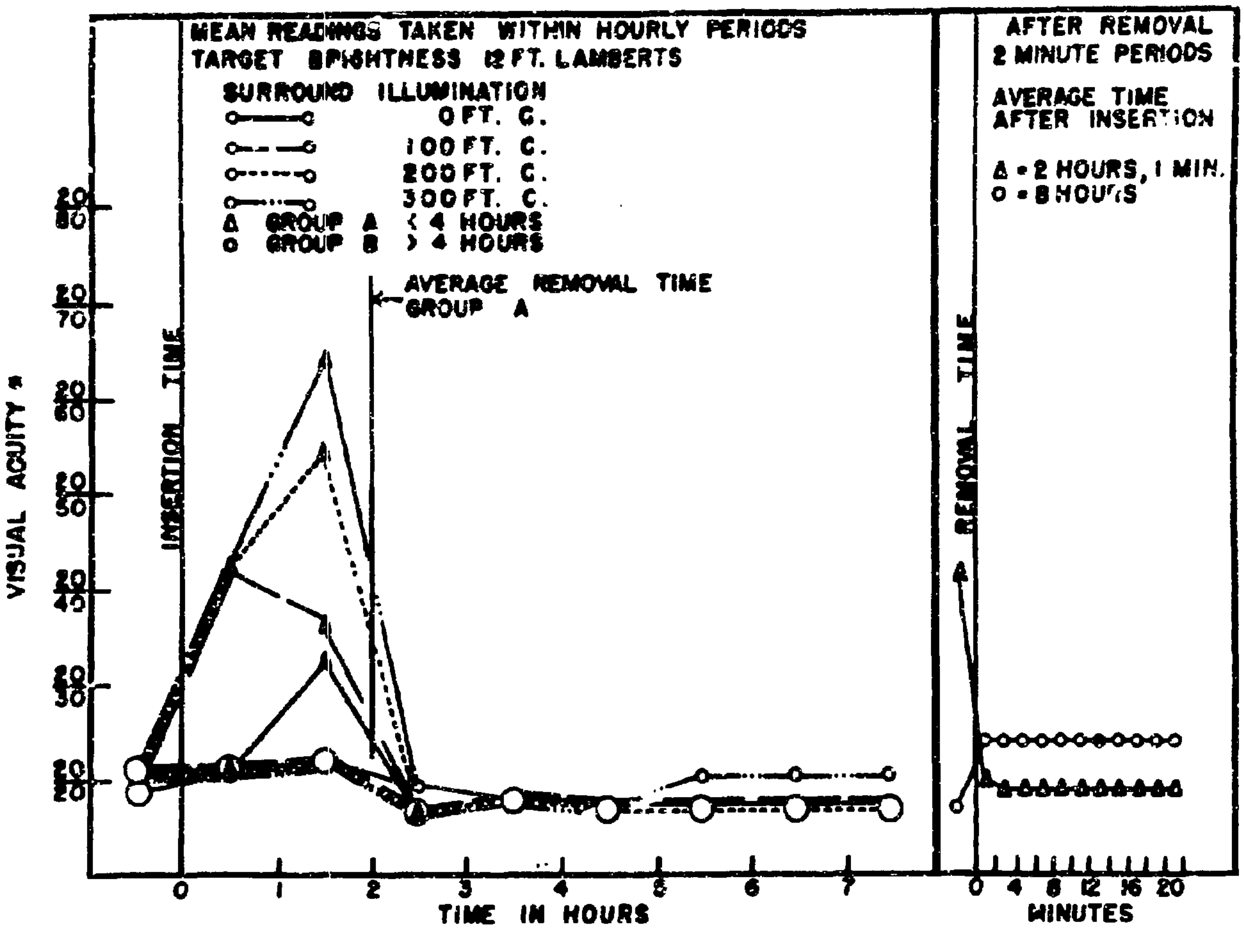


FIG. 24 TUOHY LENS VISUAL ACUITY AT 20 FEET

TIME IN HOURS MINUTES

FIG. 24 TUOHY LENS VISUAL ACUITY AT 20 FEET

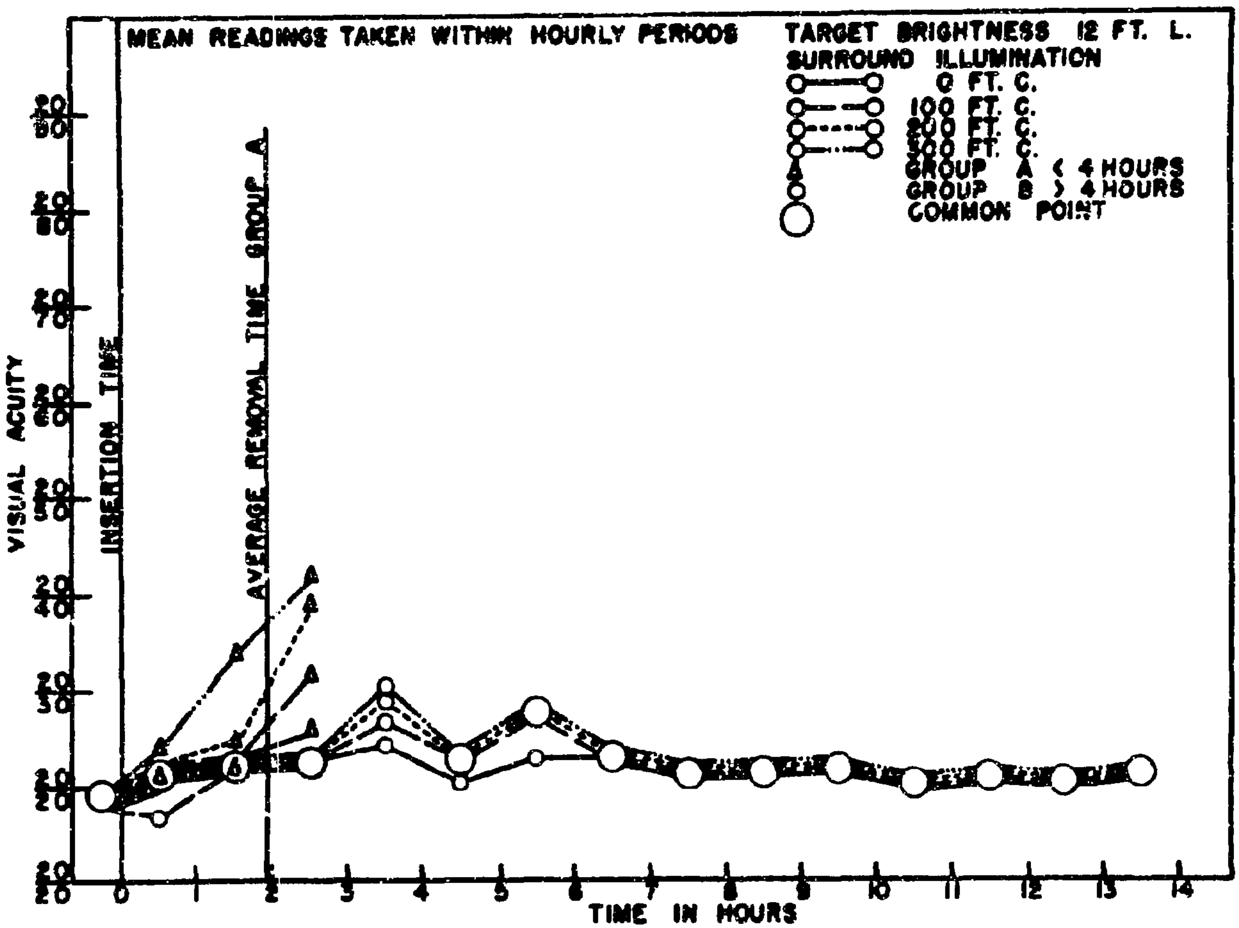


FIG. 25 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

FIG. 25 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

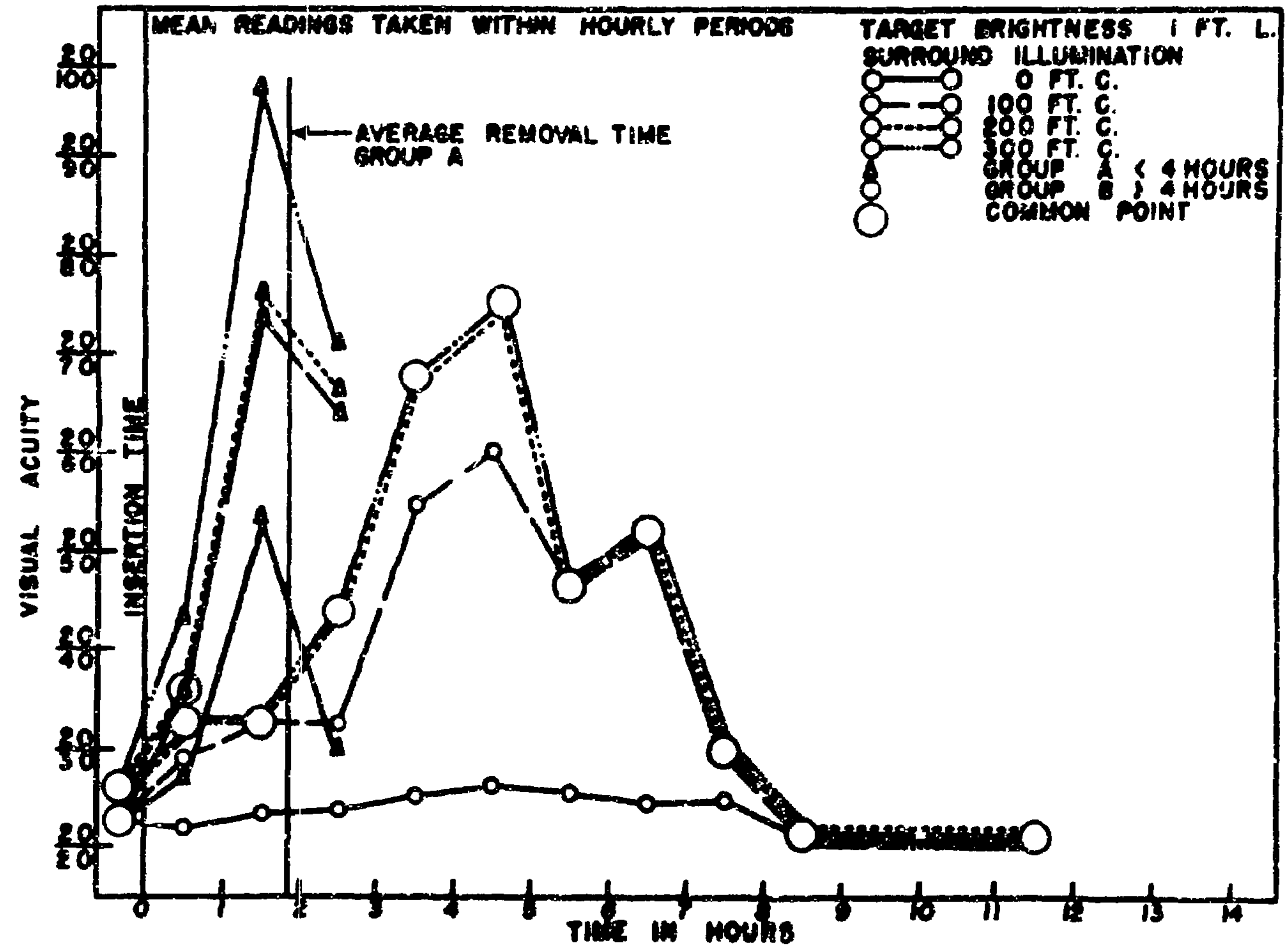


FIG. 26 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

FIG. 26 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

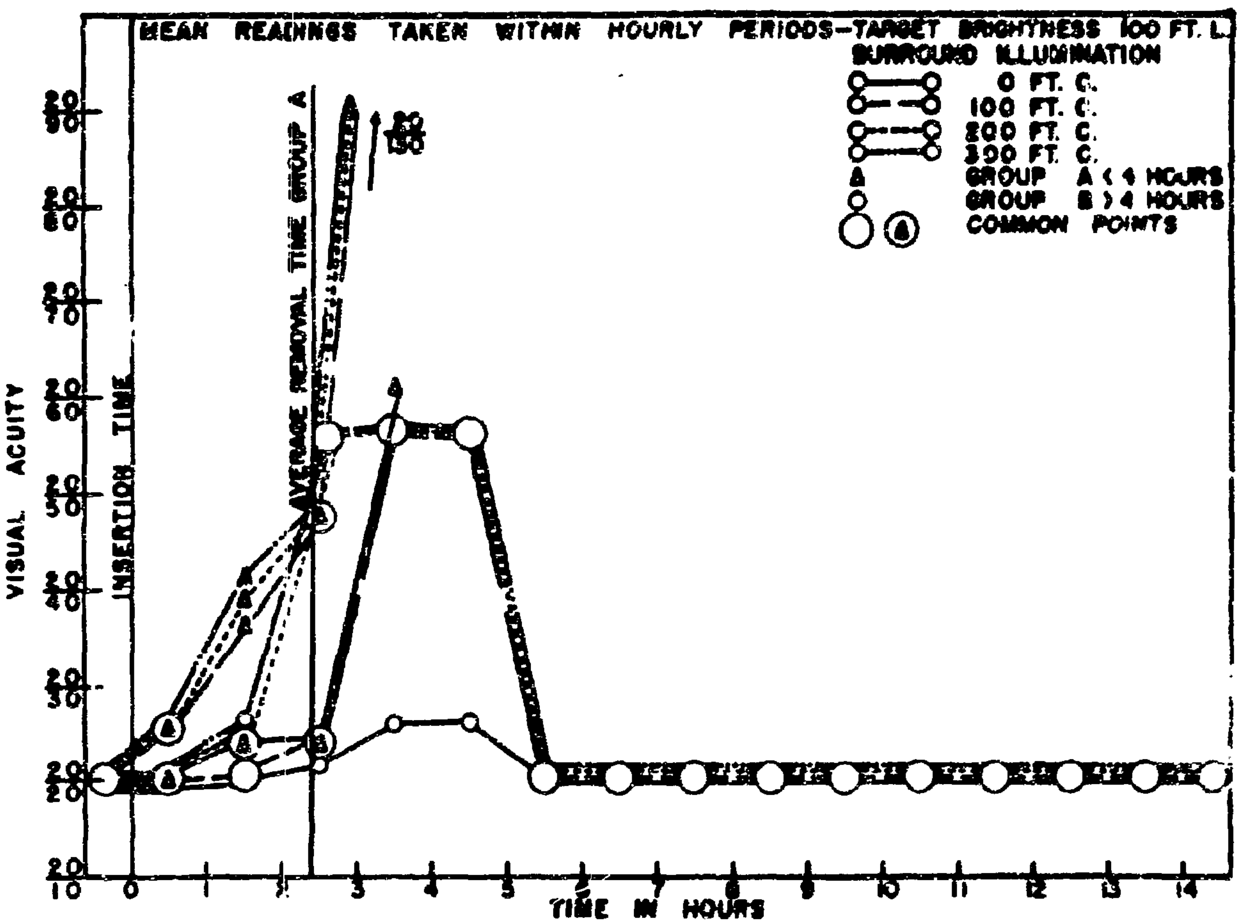


FIG. 27 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

FIG. 27 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS

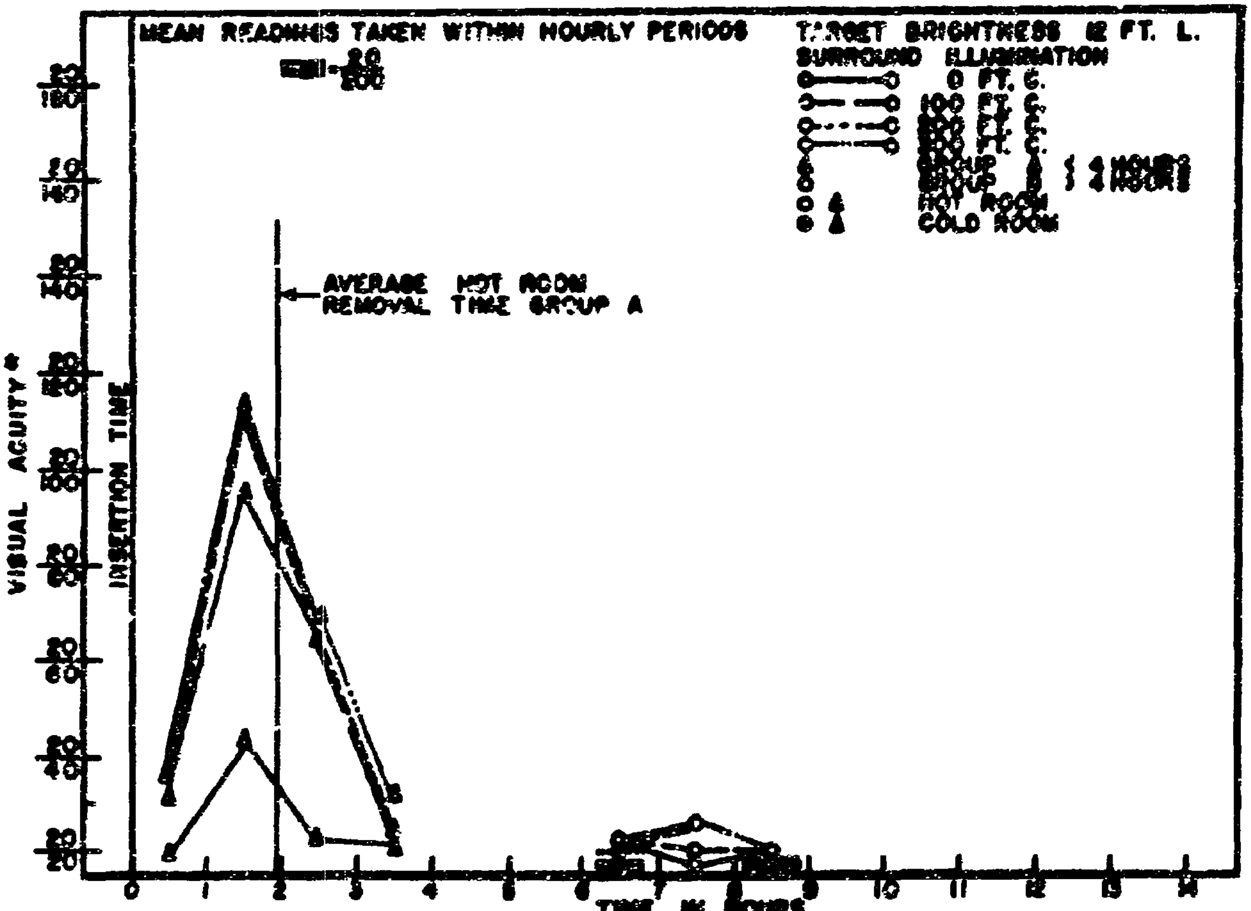


FIG. 28 TUOHY LENS VISUAL ACUITY TESTED AT 50 CENTIMETERS, HOT & COLD ROOMS

*NOTE REDUCED SCALE

FIG. 28 TUOHY LENS VISUAL ACUITY TESTED AT 50 CENTIMETERS, HOT & COLD ROOMS

*NOTE REDUCED SCALE

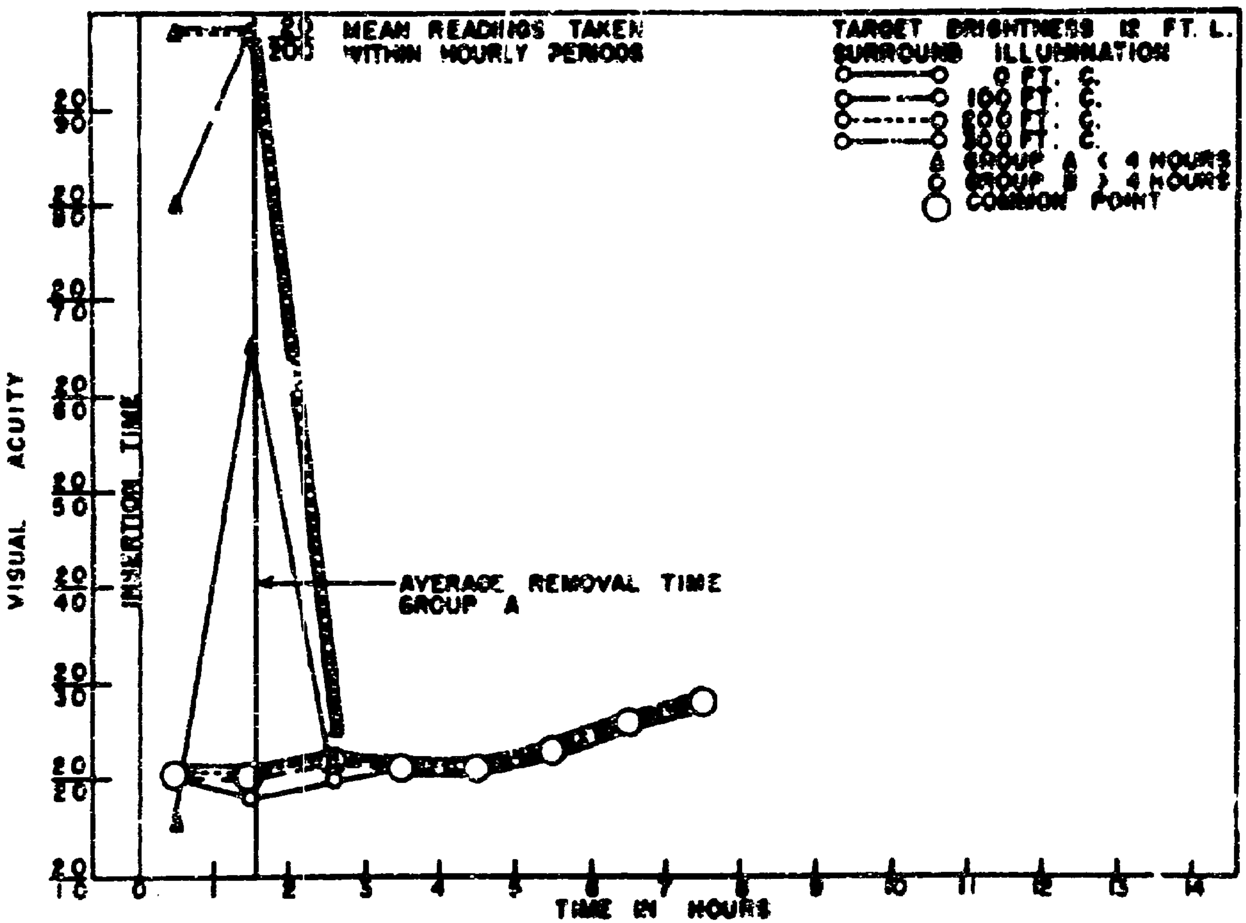


FIG. 29 TUOHY LENS, VISUAL ACUITY TESTED AT 50 CENTIMETERS IN LOW PRESSURE CHAMBER AT 20,000 FEET

FIG. 29 TUOHY LENS, VISUAL ACUITY TESTED AT 80 CENTIMETERS IN LOW PRESSURE CHAMBER AT 20,000 FEET

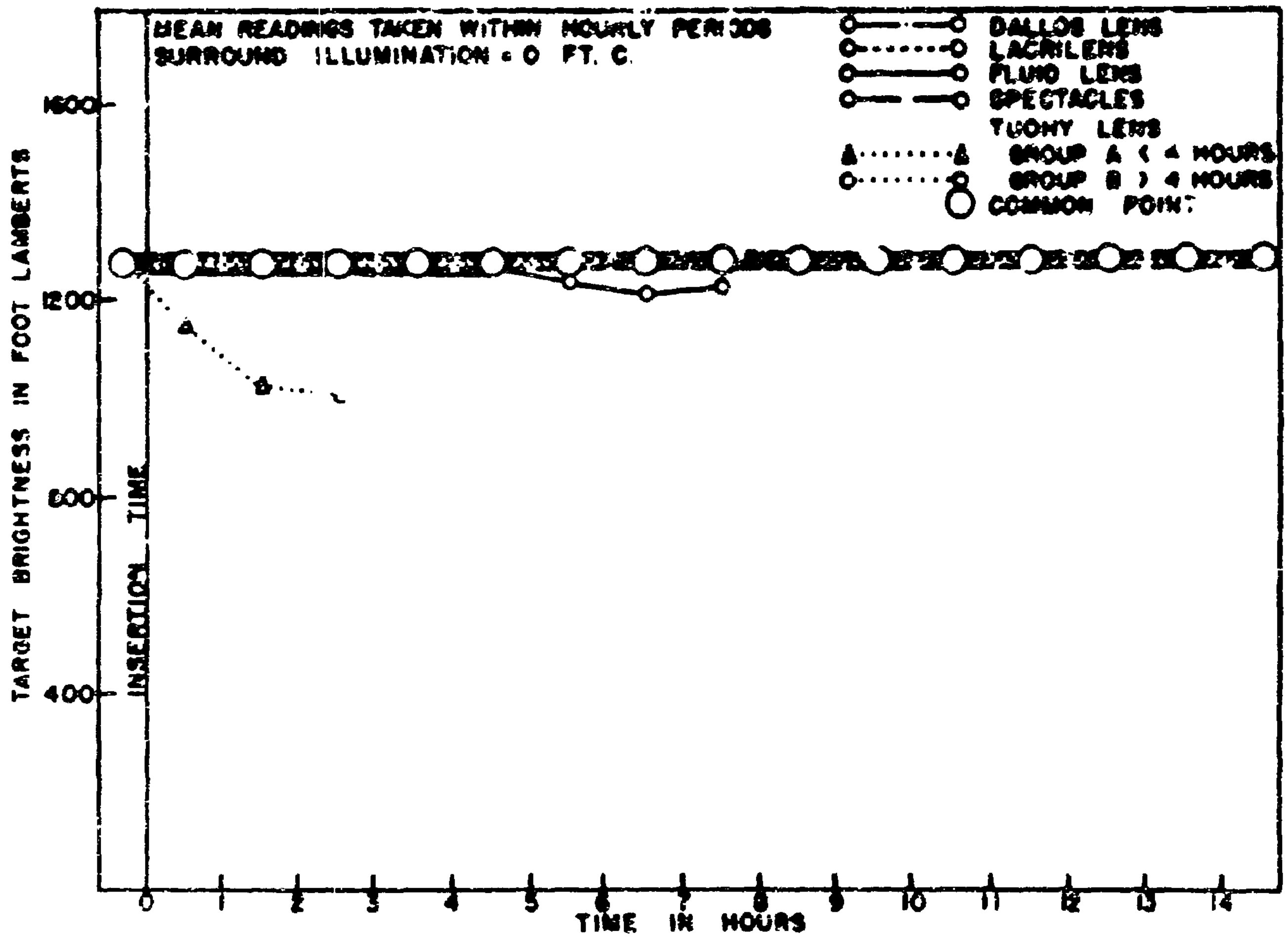


FIG. 30 TOLERANCE TO TARGET BRIGHTNESS

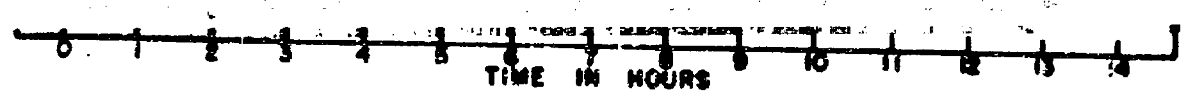


FIG. 30 TOLERANCE TO TARGET BRIGHTNESS

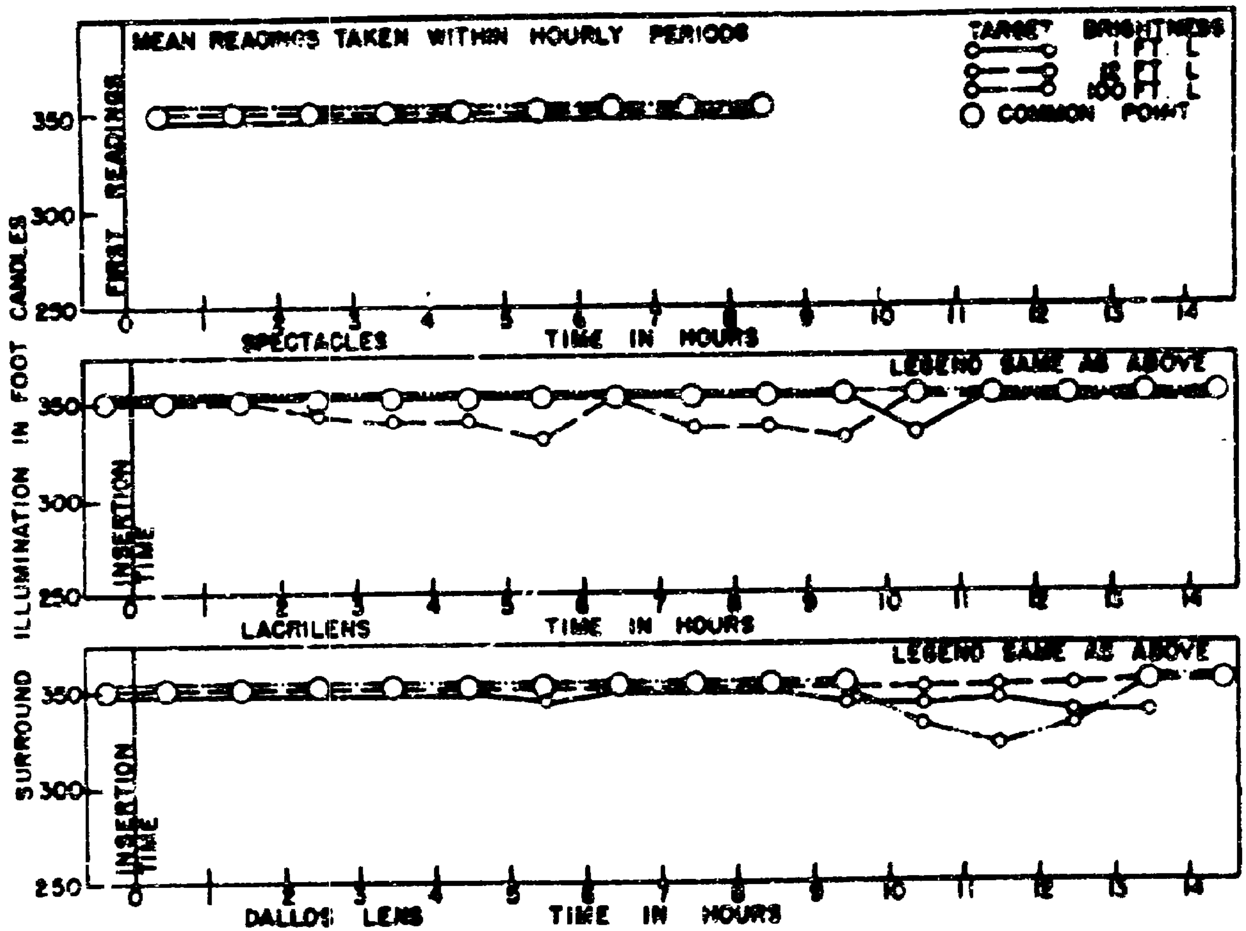


FIG. 31 TOLERANCE TO SURROUND ILLUMINATION

FIG. 31 TOLERANCE TO SURROUND ILLUMINATION

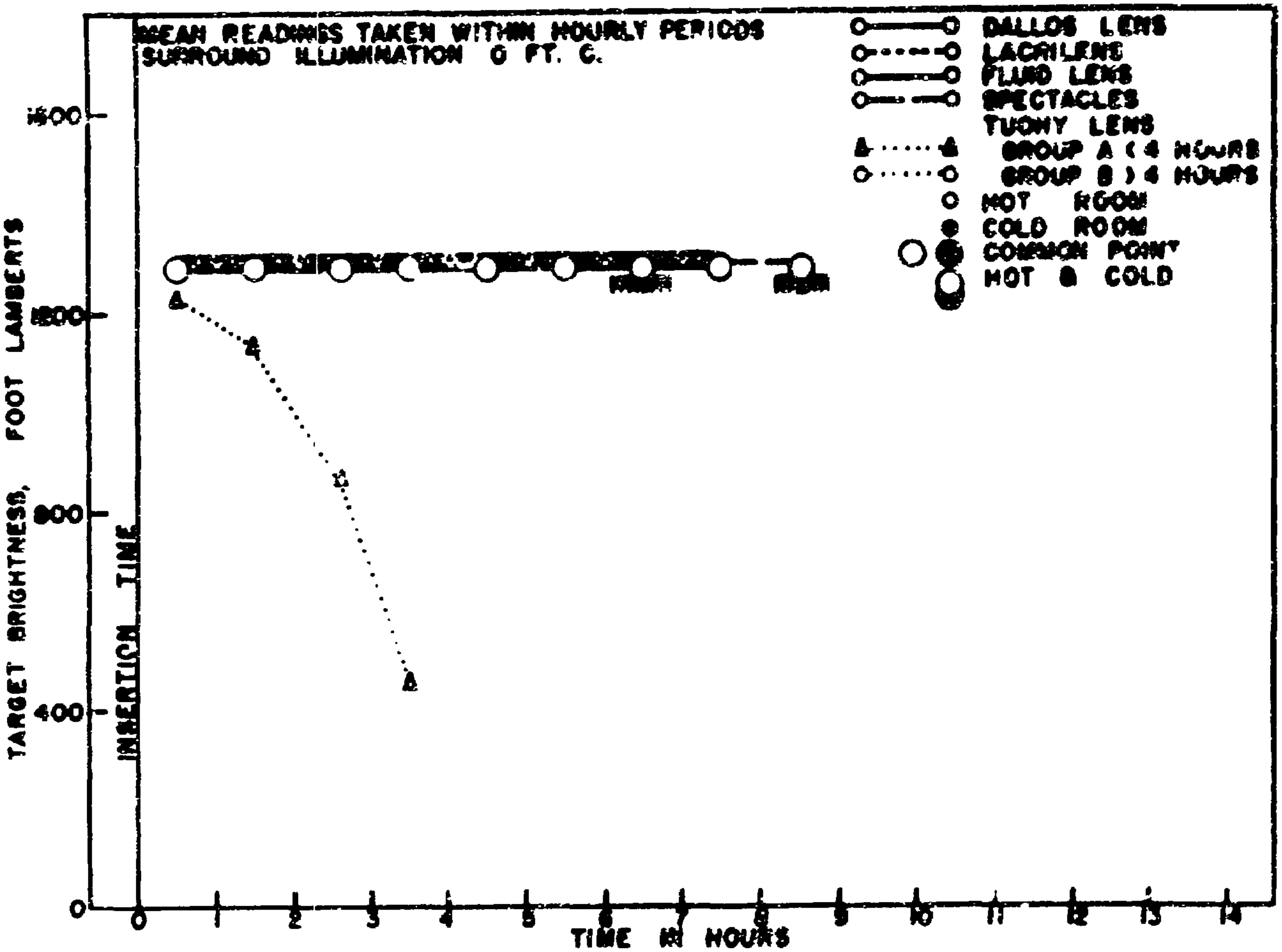


FIG. 32 TOLERANCE TO TARGET BRIGHTNESS, HOT AND COLD ROOMS

FIG. 32 TOLERANCE TO TARGET BRIGHTNESS, HOT AND COLD ROOMS

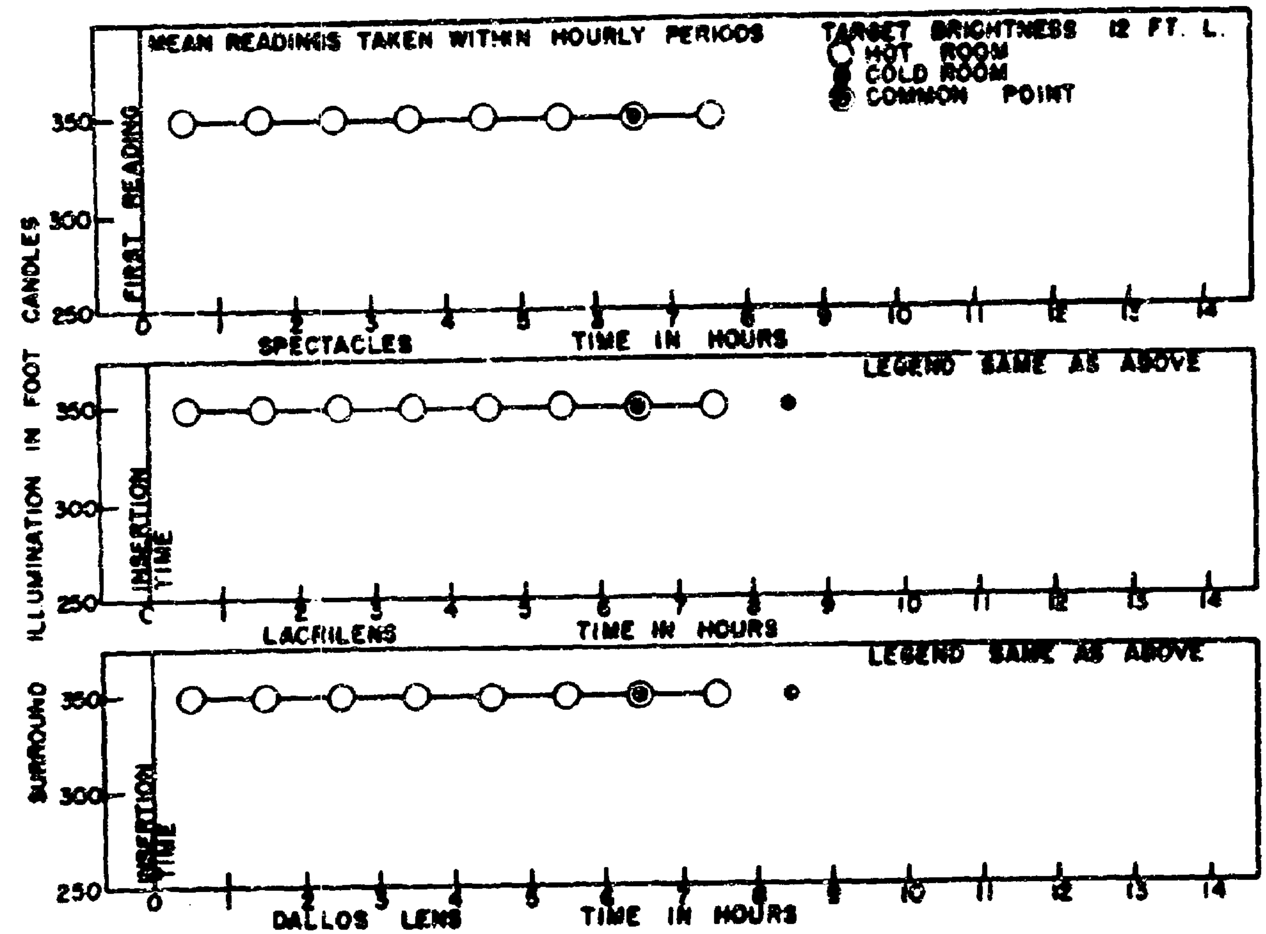


FIG. 33 TOLERANCE TO SURROUND ILLUMINATION IN HOT ROOM AND COLD ROOM

FIG. 33 TOLERANCE TO SURROUND ILLUMINATION IN HOT ROOM AND COLD ROOM

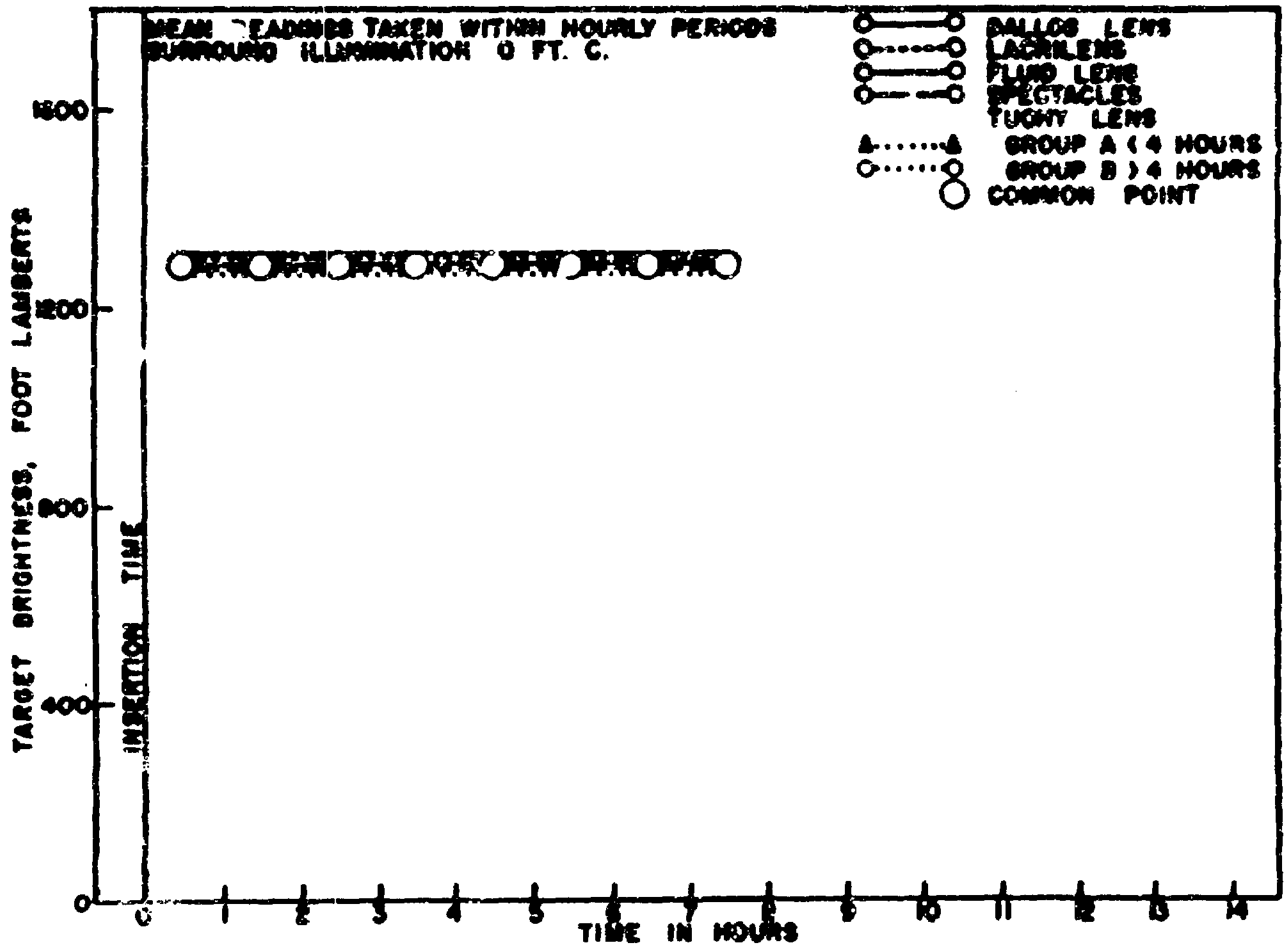


FIG. 34 TOLERANCE TO TARGET BRIGHTNESS, LOW PRESSURE CHAMBER, 20,000 FT.

FIG. 34 TOLERANCE TO TARGET BRIGHTNESS, LOW PRESSURE CHAMBER, 20,000 FT.

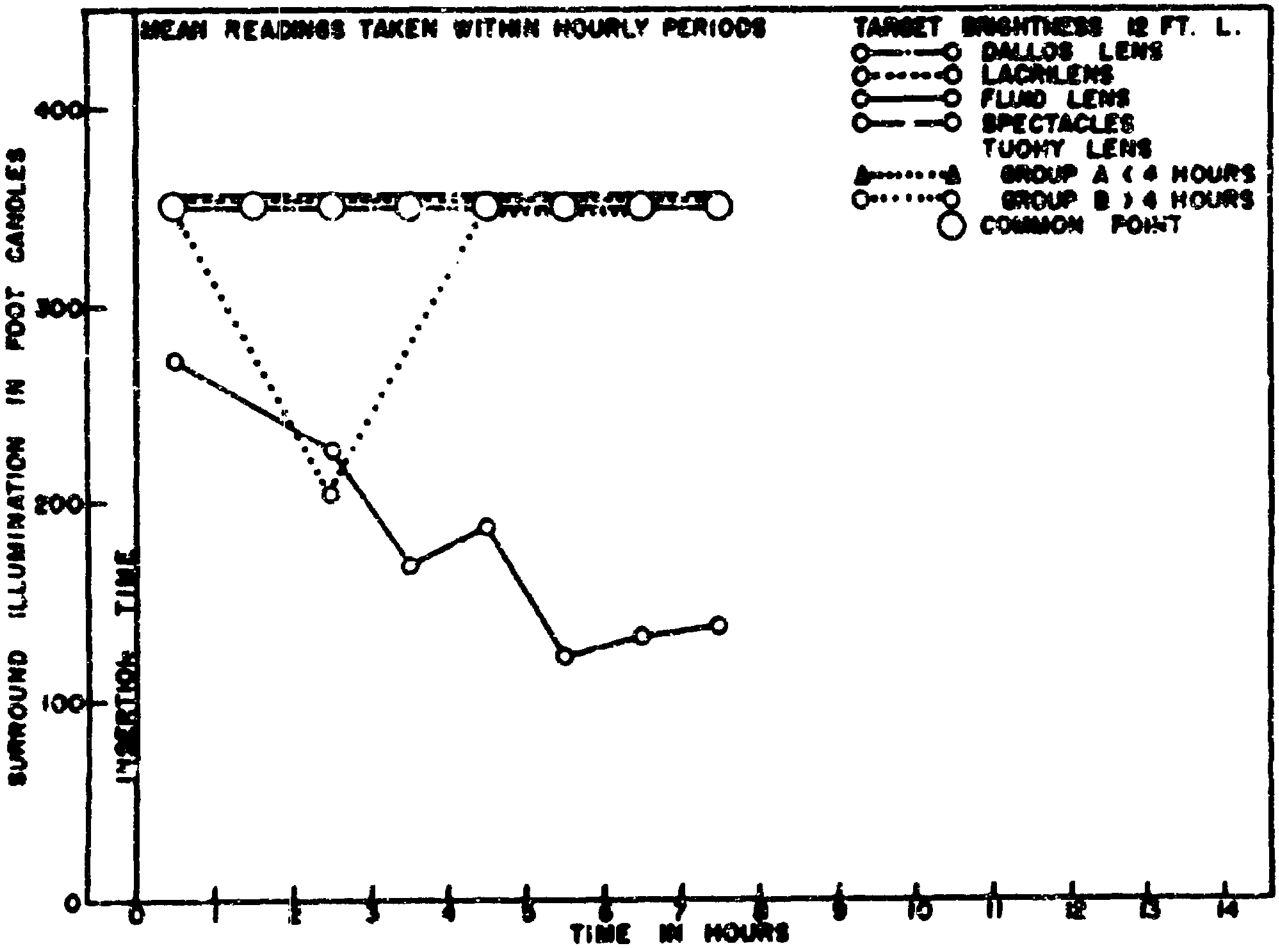


FIG. 35 TOLERANCE TO SURROUND ILLUMINATION IN LOW PRESSURE CHAMBER AT 20,000 FEET

AT 80,000 FEET

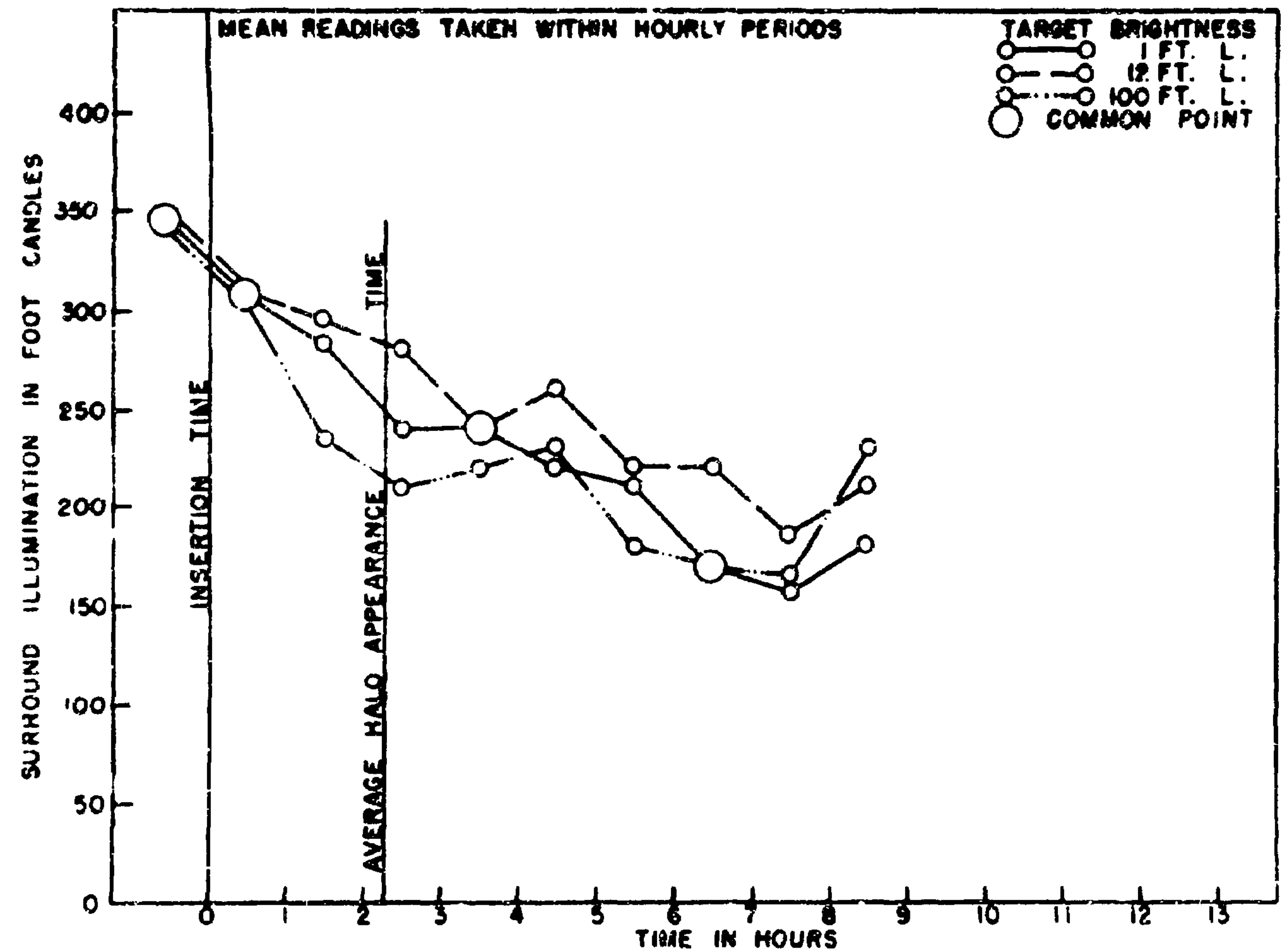


FIG. 36 FLUID LENS, TOLERANCE TO SURROUND ILLUMINATION

FIG. 36 FLUID LENS, TOLERANCE TO SURROUND ILLUMINATION

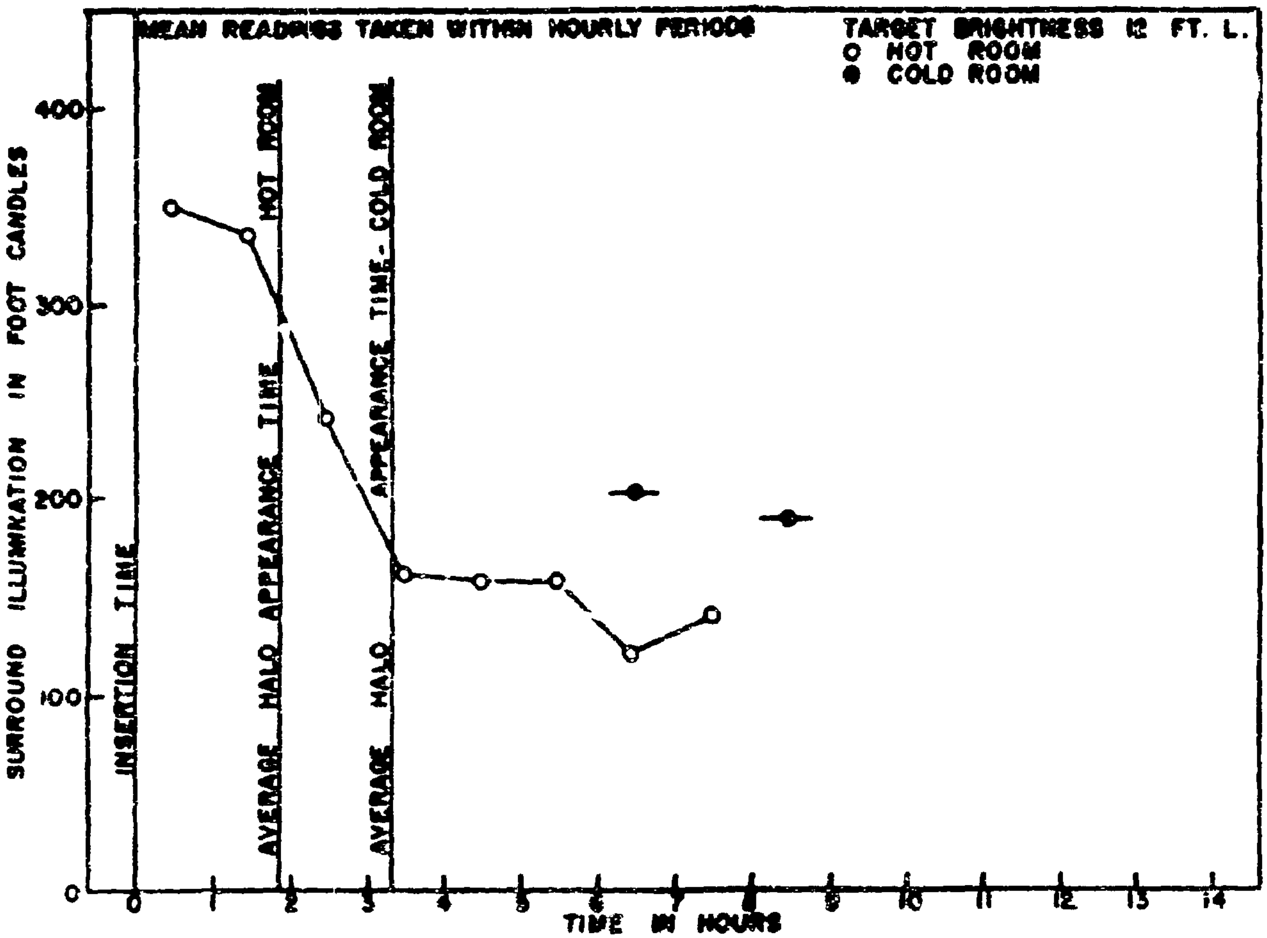


FIG. 37 FLUID LENS, TOLERANCE TO SURROUND ILLUMINATION, HOT AND COLD ROOMS

FIG. 37 FLUID LENS, TOLERANCE TO SURROUND ILLUMINATION, HOT AND COLD ROOMS

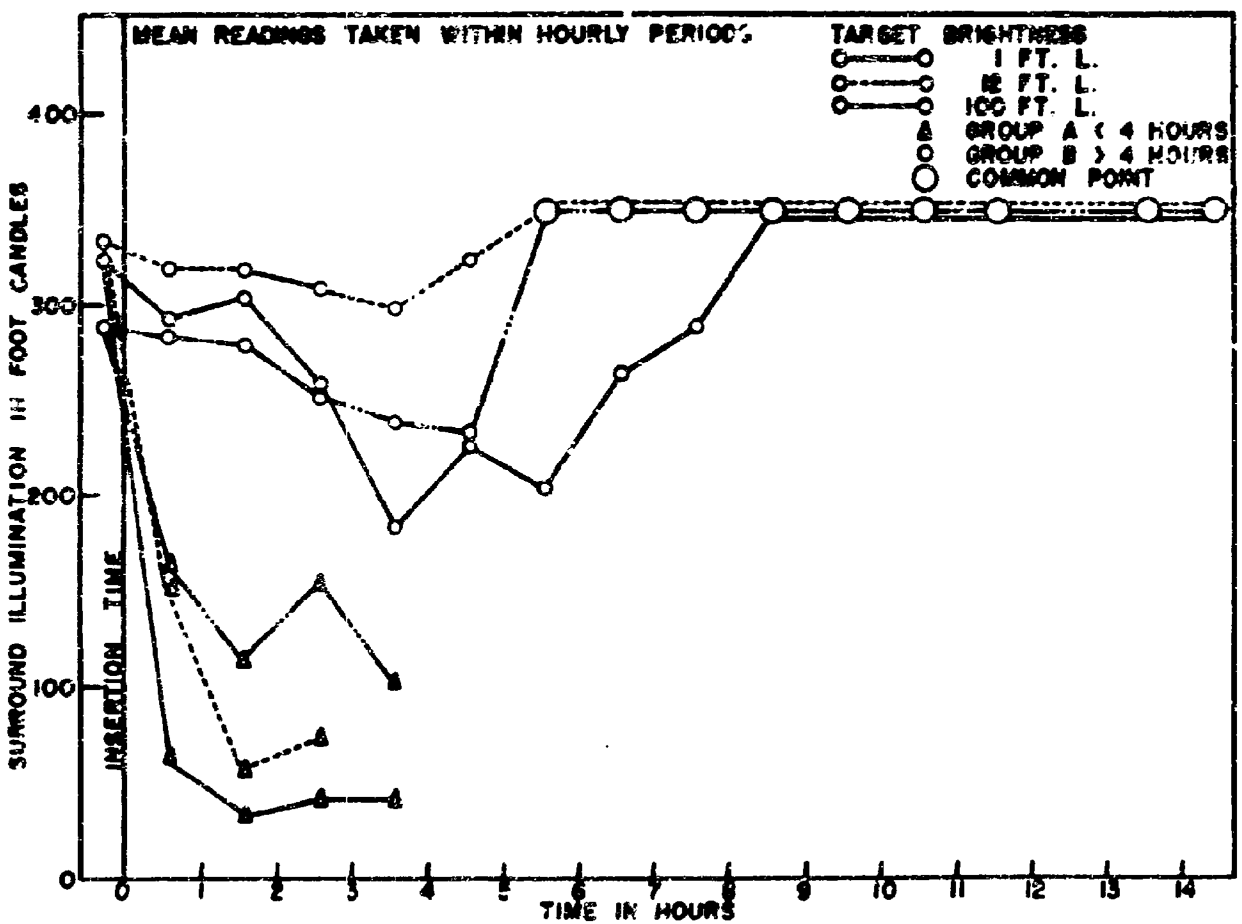


FIG. 38 TUOHY LENS, TOLERANCE TO SURROUND ILLUMINATION

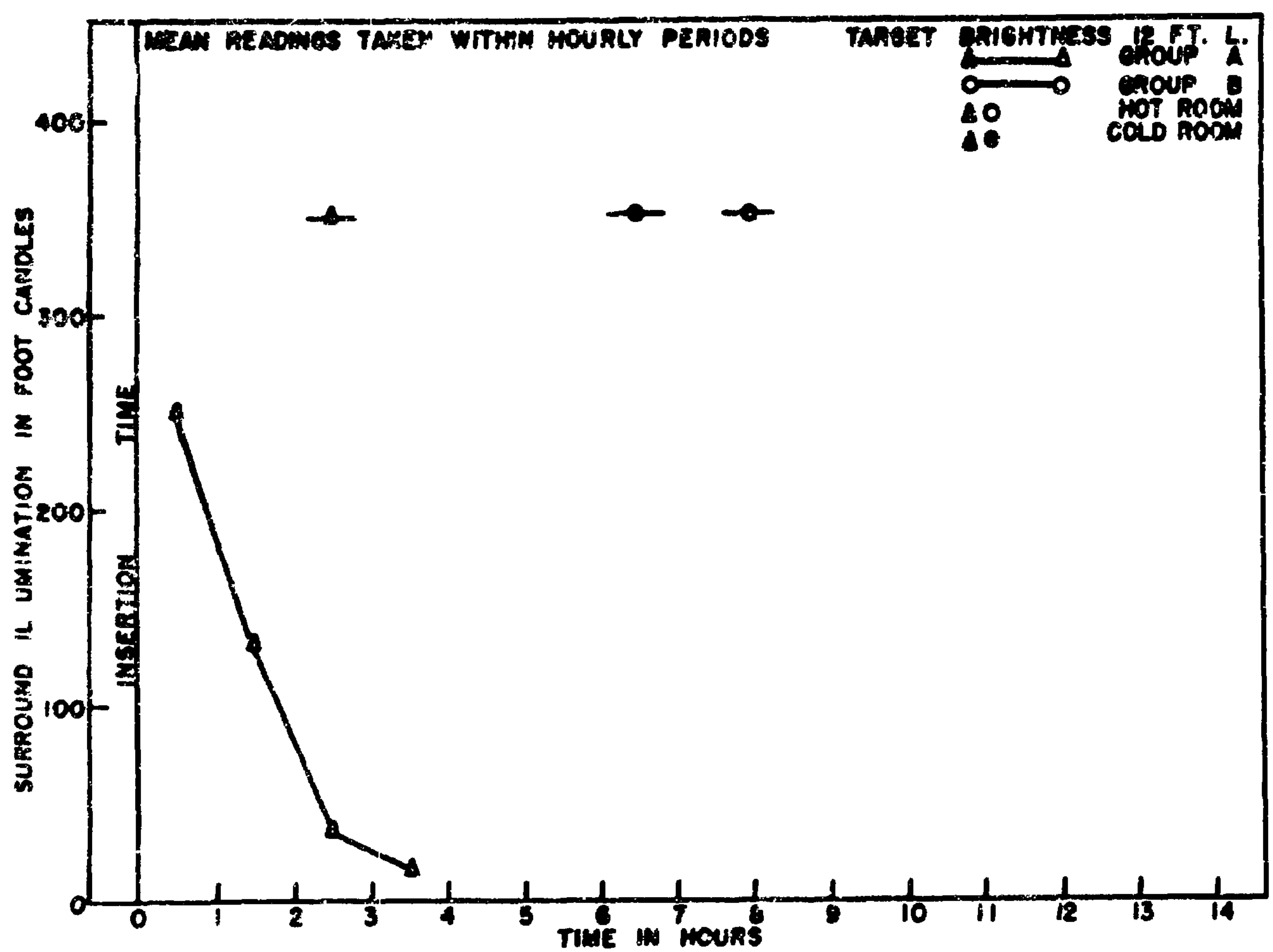


FIG. 39 TUOHY LENS, TOLERANCE TO SURROUND ILLUMINATION, HOT & COLD ROOMS

FIG. 39 TUCHY LENS, TOLERANCE TO SURROUND ILLUMINATION, HOT & COLD ROOMS

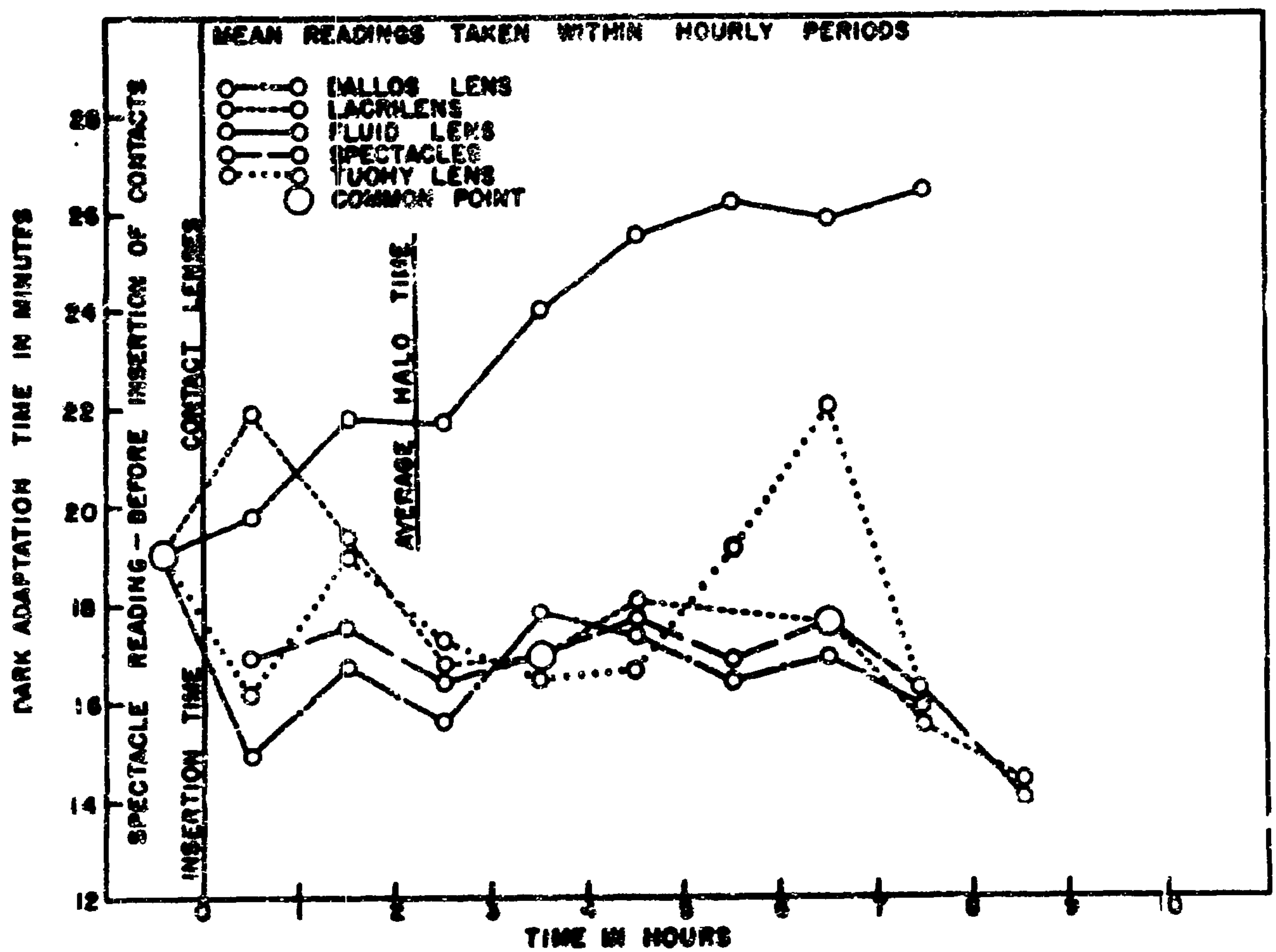


FIG. 40 TIME REQUIRED FOR DARK ADAPTATION WITH CONTACT LENSES & SPECTACLES

FIG. 40 TIME REQUIRED FOR DARK ADAPTATION WITH CONTACT LENSES & SPECTACLES

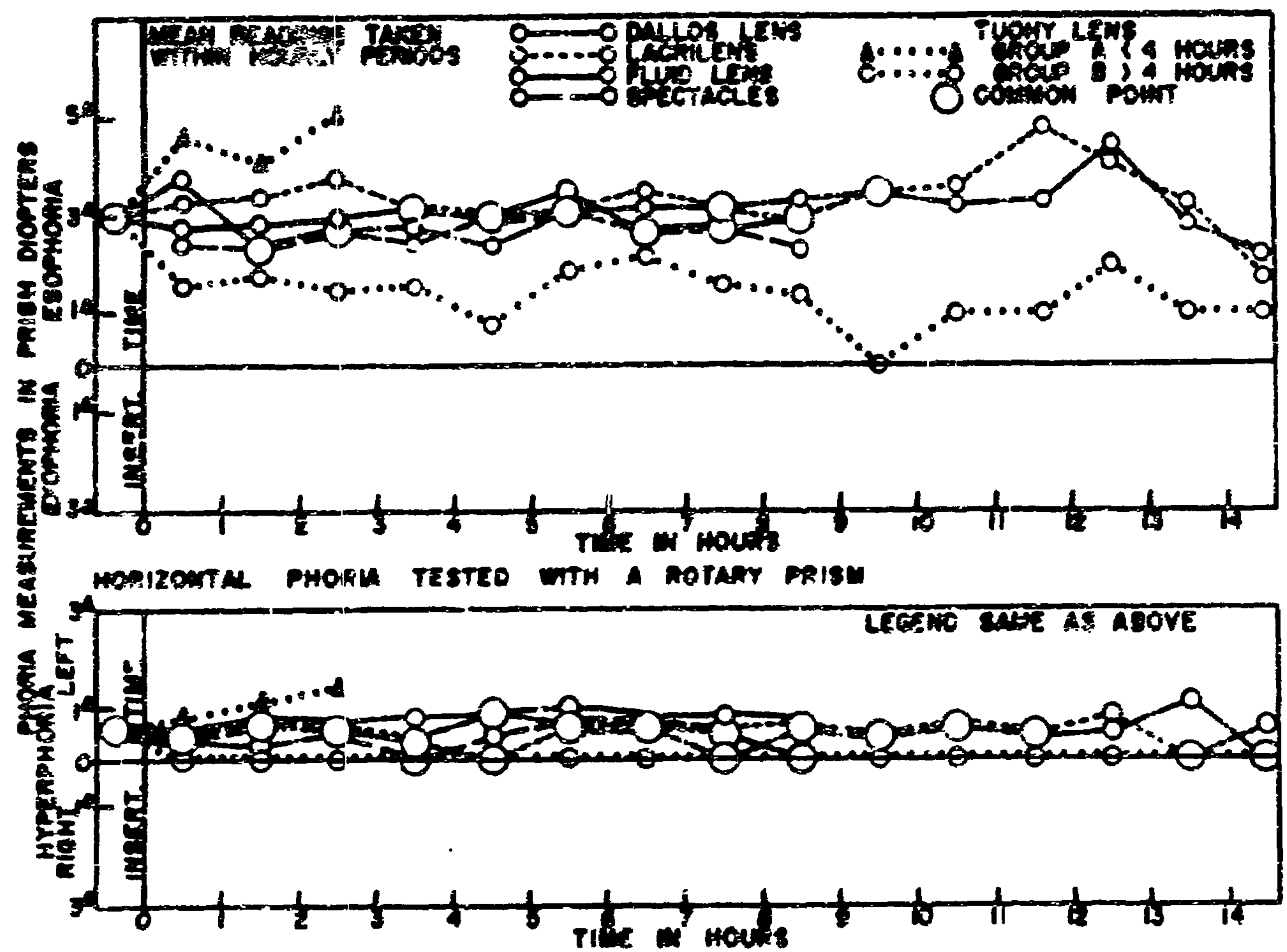
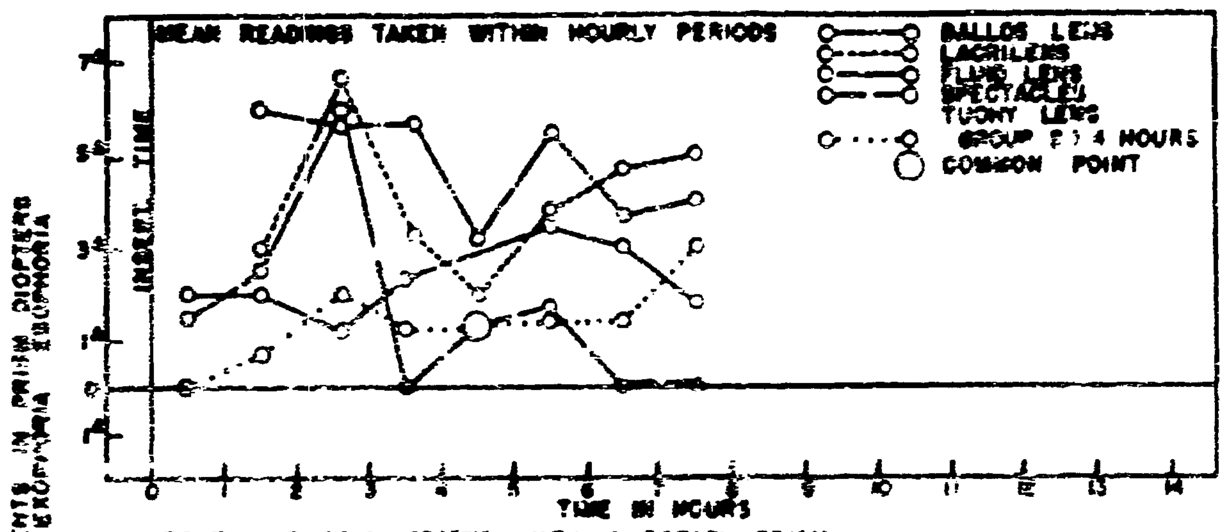
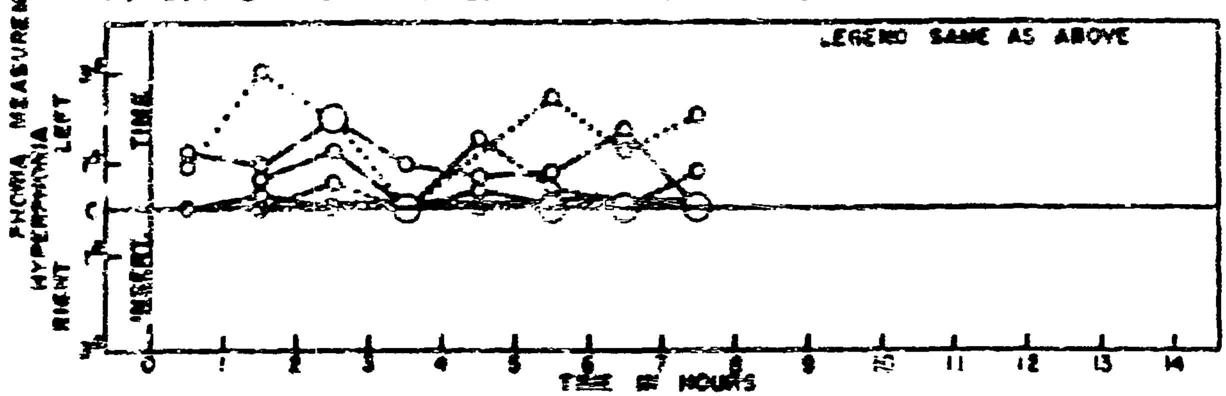


FIG. 41 PHORIA TESTED AT 20 FEET

VERTICAL PHORIA TESTED WITH A MADDOX ROD
FIG. 41 PHORIA TESTED AT 20 FEET



HORIZONTAL PHORIA TESTED WITH A ROTARY PRISM



VERTICAL PHORIA TESTED WITH A MADDOX ROD
FIG. 42 PHORIA TESTED AT 20 FEET, LOW PRESSURE CHAMBER, 20,000 FEET

FIG. 42 PHORIA TESTED AT 20 FEET, LOW PRESSURE CHAMBER, 20,000 FEET

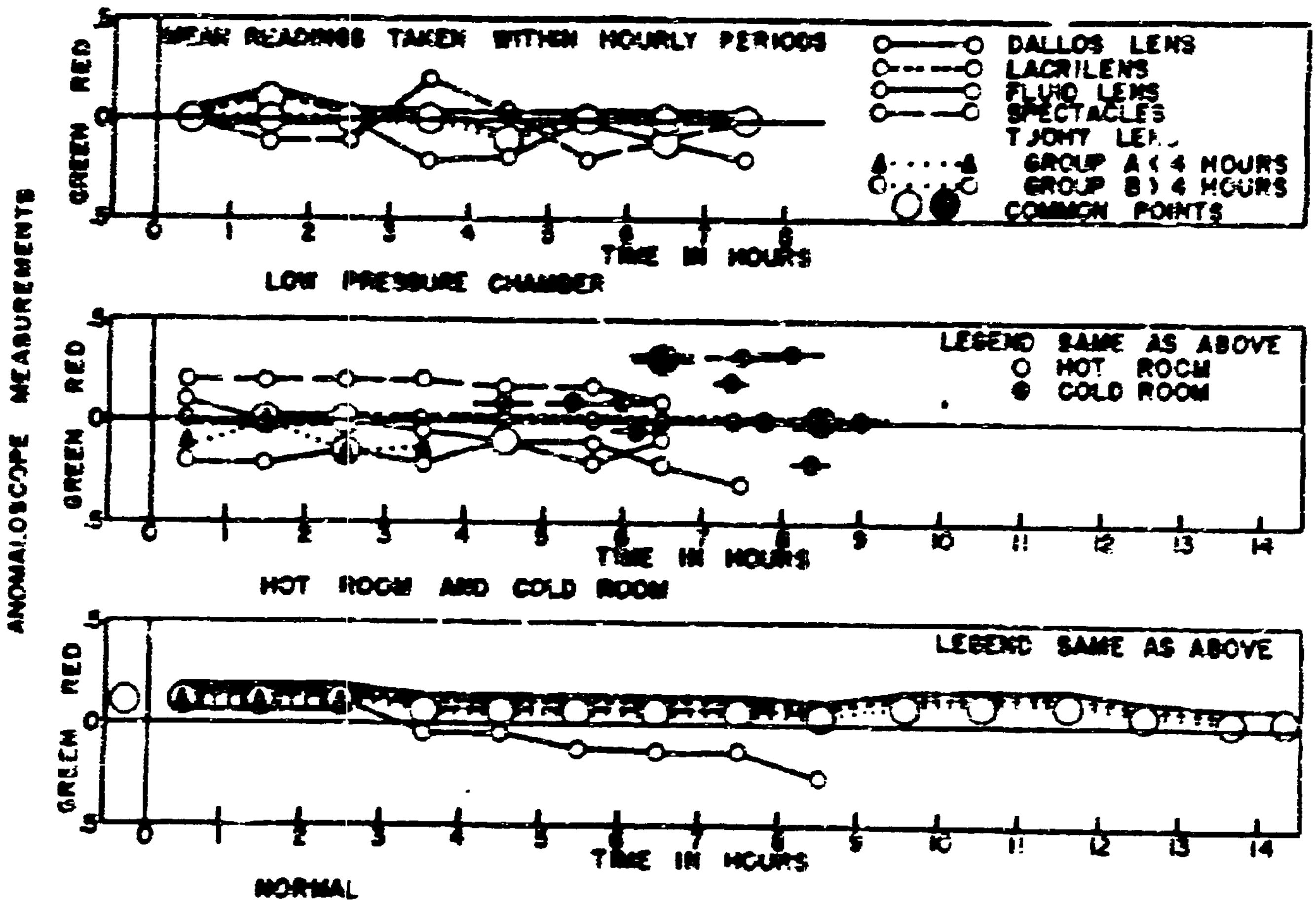


FIG. 43 COLOR VISION TESTED WITH AN ANOMALOSCOPE

Reproduced by
Armed Services Technical Information Agency
DOCUMENT SERVICE CENTER
KNOTT BUILDING, DAYTON, 2, OHIO

AD-1544

Reproduced From
Best Available Copy

UNCLASSIFIED